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ABSTRACT

Views on ways the U.S. tax code might be used to stimulate investment in research and development were presented at this hearing. Witnesses represented industry and universities and included experts on how tax policy impacts scientific research and development. The document contains testimonies and supporting documentation from the following persons: Judith S. Liebman, Vice Chancellor for Research and Dean of the Graduate School, University of Illinois at Urbana-Champaign, Illinois; Jules B. Lapidus, Director, Council of Graduate Schools, Washington, D.C.; Jerry D. Caulder, President, Mycogen Corporation, San Diego, California; John M. Swihart, President, National Center for Advanced Technologies, Washington, D.C.; Bill N. Poulos, Government Affairs Office, Apple Computer, Inc., Washington, D.C.; Robert Z. Lawrence, Senior Fellow in Economics, Brookings Institution, Washington, D.C.; Robert Eisner, Professor of Economics, Northwestern University, Evanston, Illinois; E. Allen Womack, Jr., Vice President of Research and Development Division, Babcock & Wilcox, Alliance, Ohio; and Stuart E. Eizenstat, Counsel to the Council on Competitiveness and the Council on Research and Technology, Washington, D.C. An appendix contains a copy of two parts of a publication of the Aerospace Industries Association of America titled "Key Technologies for the 1990s." The publication is an industry study of high-leverage, enabling aerospace technologies and includes four "roadmaps" or procedural guidelines to attain them. (DB)

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STIMULATING INVESTMENT IN RESEARCH AND DEVELOPMENT

HEARING

BEFORE THE

SUBCOMMITTEE ON
SCIENCE, RESEARCH AND TECHNOLOGY

OF THE

COMMITTEE ON
SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED FIRST CONGRESS

FIRST SESSION

MAY 18, 1989

[No. 29]

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Committee on Science, Space, and Technology

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*Ranking Republican Member.

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STIMULATING INVESTMENT IN RESEARCH AND DEVELOPMENT

THURSDAY, MAY 18, 1989

U.S. HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
SUBCOMMITTEE ON SCIENCE, RESEARCH AND TECHNOLOGY,
Washington, D.C.

The subcommittee met, pursuant to notice, at 9:52 a.m., in room 2318, Rayburn House Office Building, Hon. James A. Hayes [acting chairman of the subcommittee] presiding.

Mr. HAYES. The subcommittee will come to order.

Good morning. Does Doug have an opening statement? Yes, I see.

I'm going to begin the hearing with a reference to our chairman Doug Walgren's opening statement and I will serve as temporary chair until he joins us at a later moment and ask that that be put in the record without objection.

[The prepared opening statement of Mr. Walgren follows:]

OPENING REMARKS BY THE HONORABLE DOUG WALGREN (D-PA) ON STIMULATING RESEARCH AND DEVELOPMENT IN THE PRIVATE SECTOR

May 18, 1989

HOW CAN THE UNITED STATES REMAIN SO COMPETENT IN BASIC RESEARCH YET BE BEATEN SO OFTEN IN THE WORLD MARKETPLACE? WHY DO WE HAVE SUCH A HARD TIME FILLING OUR GRADUATE SCHOOLS WITH AMERICAN CITIZENS? TO WHAT EXTENT CAN THE ANSWERS TO THESE AND RELATED QUESTIONS BE FOUND IN OUR FEDERAL TAX CODE? THIS IN A NUTSHELL IS WHAT WE ARE CONSIDERING THIS MORNING.

RECENT TRENDS IN RESEARCH AND DEVELOPMENT EXPENDITURES BY THE PRIVATE SECTOR ARE TROUBLESOME. U.S. CIVILIAN RESEARCH AND DEVELOPMENT EXPENDITURES AS A PERCENTAGE OF GNP ARE WELL BELOW THOSE OF OUR

COMPETITORS. THIS OCCURS EVEN THOUGH WE KNOW THAT RESEARCH AND DEVELOPMENT EFFORTS LEAD TO THE CREATION OF NEW JOBS, NEW MARKETS AND NEW OPPORTUNITIES WHICH ARE AN IMPORTANT UNDER PINNING OF THE AMERICAN QUALITY OF LIFE.

IN 1985 JAPAN AND WEST GERMANY SPENT 2.5% OF THEIR GNP ON CIVILIAN R&D. IN THAT SAME YEAR WE SPENT LESS THAN 2% OF OUR GNP ON CIVILIAN R&D. THIS TREND HAS BECOME MORE PRONOUNCED IN RECENT YEARS.

WE ALSO HAVE TO BE CONCERNED ABOUT OUR DWINDLING SUPPLY OF HIGHLY TRAINED SCIENTISTS AND ENGINEERS WHO ARE VITAL TO OUR RESEARCH AND DEVELOPMENT EFFORT AND ABOUT OUR CONTINUING DEPENDENCE ON STUDENTS AND PROFESSIONALS FROM OVERSEAS. THE NUMBER OF U.S. CITIZENS EARNING

DOCTORATES IN SCIENCE AND ENGINEERING HAS BEEN DECLINING SINCE 1975 WHILE THE NUMBER OF FOREIGN STUDENTS EARNING DOCTORATES HAS STEADILY INCREASED. IT IS CLEAR THAT OUR YOUTH ARE AS BRIGHT AS EVER, BUT EQUALLY CLEAR THAT CAREERS IN SCIENCE DO NOT ATTRACT THEM IN THE NUMBERS IT MUST. WE MUST LEARN WHAT KIND OF INCENTIVES ARE NECESSARY TO ATTRACT GRADUATE STUDENTS TODAY AND WHAT IT TAKES TO PERMIT THEM TO STAY THE COURSE.

OVER THE YEARS, THE FEDERAL GOVERNMENT HAS PLAYED AN IMPORTANT ROLE BOTH IN SUPPORTING R&D AND IN PROVIDING INCENTIVES THAT STIMULATE LONG-TERM R&D INVESTMENT BY THE PRIVATE SECTOR. SOME OF THESE PROGRAMS HAVE WORKED. OTHERS HAVE NOT. THE 1986 TAX ACT MADE MAJOR CHANGES AFFECTING BOTH RESEARCH AND DEVELOPMENT AND

STUDENTS' TAX LIABILITIES. DECISIONS MUST BE MADE SOON WHETHER TO EXTEND OTHER TAX INCENTIVES SUCH AS THE R&D TAX CREDIT. THEREFORE, TODAY'S TESTIMONY IS VERY TIMELY AS THE CONGRESS DEVELOPS A TAX POLICY WHICH PROMOTES U.S. COMPETITIVENESS AND WORKS TO IMPROVE THE IMPACT OF THE OTHER PROGRAMS TO ENCOURAGE INDUSTRY TO INVEST FOR THE FUTURE, AND TO MOVITATE STUDENTS TO STUDY SCIENCE AND ENGINEERING.

WE HAVE TWO PANELS OF WITNESSES REPRESENTING INDUSTRY AND UNIVERSITIES, AND A PANEL OF EXPERTS IN THE AREA OF TAX POLICIES AFFECTING SCIENTIFIC RESEARCH AND DEVELOPMENT. I WANT TO WELCOME OUR DISTINGUISHED WITNESSES TODAY.

Mr. Hayes. Also, I have an opening statement and I make the same request, and I'll not burden you with the additional time and we'll have an opportunity for questions later.

[The prepared opening statement of Mr. Hayes follows:]

STATEMENT OF

CONGRESSMAN JIMMY HAYES

7TH DISTRICT OF LOUISIANA

SUBCOMMITTEE ON SCIENCE, RESEARCH & TECHNOLOGY

HEARING ON

THE EFFECT OF FEDERAL POLICIES ON

RESEARCH & DEVELOPMENT EXPENDITURES

Mr. Chairman, I am extremely pleased that this subcommittee has convened this hearing in order to review how effective our federal policies are in fostering research and development activities. As a firm believer in this nation's ability to continue as the world leader in new technologies, I am concerned that we have failed to respond to a changing global market where competitors have refined their gameplans in order to beat us in this arena. Furthermore, while paying a lot of attention to our international trade imbalance, I fear that we have lost sight of a major cure; improved productivity and new innovations.

With these concerns in mind, I am interested to hear from each of the panels testifying here today. In particular, I am curious as to their suggestions on how the federal government can best assist universities and industry in developing new or improved technologies in the most cost-effective manner.

The fact that nearly 50% of all patents awarded last year went to foreign-owned firms, while in 1963 only 18% went to foreigners, is a figure that concerns me. Furthermore, the fact that West Germany, Japan, France, and the U.K. all do more non-defense R&D than the U.S., as a percentage of their GNP, seems to reinforce my concern that we may be slowly beginning to lag behind our competition.

Fortunately, I believe that we have several avenues to pursue in order to revitalize or assist those areas that may need federal attention. For example, I believe that this hearing will shed light upon the need for strengthening each level of our educational system so that we can produce scientists, engineers and technicians, equipped with the skills necessary to succeed. Adjustments in our tax code may also be able to foster growth, as could incentives to develop consortiums. One area that may also need inspection involves anti-trust laws and their impact on specific industries' ability to create and capitalize on new advances.

Again, I appreciate this opportunity to address the issue of federal involvement in R & D activities and look forward to our panels' comments.

Mr. **Hayes**. I would then turn to our ranking Republican whom I see also has an opening statement.

Mr. **Boehlert**. And I'm going to burden you with it. Thank you, Mr. Chairman.

It's a pleasure to be with you today to discuss how the tax code can improve our flagging ability to compete in the international marketplace.

Some argue that such tax provisions "distort" business decisions, but I think provisions like the R&D tax credit correct distortions that are inherent in the private sector.

All the pressures that are exerted on industry from the private sector militate in the direction of short-range payoffs. The Government ought to be putting pressure in the opposite direction to keep factors in balance.

When the tax code encourages R&D to the same degree it encourages massive mergers, which result in cuts in R&D, then we will have eliminated distortion from the tax code.

I am a co-sponsor of H.R. 1416 which would make the R&D tax credit permanent. However, I'm certainly open to suggestions on how to make that provision more effective. I hope today's witnesses will be supplying such advice.

I'm also interested in hearing what our university panel can tell us about the impact tax law changes may have had on graduate school enrollment. There is a fear that in the interest of "equity" we may have added to the disincentives that discourage students from continuing on to graduate school, thereby making us not only more equal, but poorer in the long run.

The best way to deal with this provision may be the route the National Science Foundation has taken: upping the graduate stipend to keep the after-tax income unchanged. I'll be interested in learning how many organizations have tried this approach.

"Taxes," Oliver Wendell Holmes reminded us, "are the price we pay for a civilized society." I don't see why we should not use reasonable tax incentives to advance that civilization.

Thank you, Mr. Chairman.

[The prepared opening statement of Mr. Boehlert follows:]

REP. SHERWOOD BOEHLERT (R-NY)
OPENING STATEMENT FOR R&D TAX HEARING
May 18, 1989

Mr. Chairman:

It's a pleasure to be with you today to discuss how the tax code can improve our flagging ability to compete in the international marketplace.

Some argue that such tax provisions "distort" business decisions. But I think measures like the R&D tax credit correct distortions that are inherent in the private sector. All the pressures that are exerted on industry from the private sector militate in the direction of short-range pay-offs. The government ought to be putting pressure in the opposite direction to keep factors in balance.

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The best way to deal with this provision may be the route the National Science Foundation has taken: upping the graduate stipend to keep the after-tax income unchanged. I'll be interested in learning how many organizations have tried this approach.

"Taxes," Oliver Wendell Holmes reminded us, "are the price we pay for a civilized society." I don't see why we shouldn't use reasonable tax incentives to advance that civilization.

Thank you.

Mr. **Hayes**. Does the gentlelady from Rhode Island have a statement?

Ms. **Schneider**. Mr. Chairman, in the interests of time, I too will be happy to include my statement in the record, if that is permitted.

I will say that I appreciate the fact that we are calling this hearing together today, because clearly the impact of the tax structure on the competitiveness stature of this nation's business and industry is critical, and as a leader in the competitiveness caucus and pushing for the R&D tax credit, I think that there are many other opportunities.

I look forward to hearing from the witnesses about what some of those opportunities might be.

Thank you, Mr. Chairman.

[The prepared opening statement of Ms. Schneider was not received at press time.]

Mr. **Hayes**. Thank you very much.

Let us go ahead to our first panel. Dr. Judith Liebman, Vice-Chancellor for Research and Dean of the Graduate College, University of Illinois at Urbana-Champaign and Dr. Jules LaPidus—Doctor, I don't know if you'd like the South Louisiana pronunciation of that, or whatever corruption they've given it here in the District of Columbia, I would have said "La Padue" but I suspect that you can't live with that here in the District.

Dr. **LaPidus**. That's right, "LaPidus" is fine.

Mr. **Hayes**. "LaPidus" is probably also more phonetic in the phone book. Welcome to you, and you are the Director of the Council of Graduate Schools in Washington, D.C. We thank both of you and please proceed in whatever order you may have determined among yourselves.

STATEMENT OF JUDITH S. LIEBMAN, VICE CHANCELOR FOR RESEARCH AND DEAN OF THE GRADUATE COLLEGE, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN, ILLINOIS

Dr. **Liebman**. Thank you, Mr. Chairman, for providing us with the opportunity to speak on these issues.

I am deeply concerned about the implications of tax issues and current demographic trends on doctoral education specifically, and on graduate education in general.

Doctoral education has, directly or indirectly, benefitted virtually every major scientific development of the last 30 years. Examples include not only our space program, and the discovery of superconductivity, but also development of computer technology now integrated into our daily lives from automobiles to VCRs.

The maintenance and growth of modern society requires a special kind of intellectual nourishment, a continuing inflow of new ideas, discoveries and technologies. Doctoral education trains those will generate and disseminate these new ideas.

Although an increased demand for Ph.D.s is predicted, the supply forecast is gloomy. Already there is a shortage of engineering faculty nationwide, and a shortfall of 7,500 annually—of natural science and engineering Ph.D.s annually—is predicted after the turn of the century. Unless we take action now, we will not be able to sustain and increase our country's rate of technology and economic growth.

The problem is made worse by the fact that there are growing employment opportunities for Ph.D.s in nonacademic settings, partly due to increased R&D efforts in the private sector, and also, a new awareness in the private sector of the importance of international trade which has generated demand for more graduate study in foreign languages and international studies.

Our college population is dropping now and will continue to drop for a bit, but then increase rapidly to above the current level by the year 2005. At the same time this increase in student load is occurring, there is expected to be a decrease in the university faculties available to teach because many of the professors hired in the post-Sputnik expansion will be reaching retirement.

Where are the replacement faculty to come from? Because of the length of time needed for graduate work, these replacements must come from students currently entering or enrolled in college. Thus, the problem is urgent and solutions must be implemented now.

Demographic trends are of even more concern in the science and engineering area. An increasing proportion of our working population are women and minorities. Those groups have traditionally been underrepresented in the fields of science and engineering.

The impact of these demographic trends upon doctoral degree recipients is already visible. The percentage of U.S. citizens receiving doctorates has decreased over the last decade, and this drop has been particularly severe in engineering.

In 1970, 73 percent of the doctorates in engineering were awarded to U.S. students; by 1986, it had dropped to less than 41 percent. The accomplishments and contributions of students from other countries have been and continue to be significant, particularly in science and engineering.

But at most, only about 70 percent of foreign degree recipients currently remain in the United States, and that percentage is expected to drop as students' home countries provide more incentives for them to return home. We simply cannot afford to remain dependent upon a foreign supply of scientists and engineers to meet our research and development needs.

How do we then increase the number of graduate students? A continuing stable supply of fellowships, traineeships, and assistantships is the primary answer. It has worked before, and it will work again.

After World War II, the Federal Government played an active and very successful role in the development and training of graduate students, through the sponsoring of fellowships, traineeships, and the funding of university research. Under this expansion, the number of Federally- funded graduate student stipends rose from 1,600 in 1954 to over 80,000 in 1969.

But there was a sudden decline in Federal support beginning in 1970. In a five-year period, most traineeships were eliminated, and the number of fellowships were greatly reduced. We also lost doctoral support under the GI Bill.

This declining financial support has been made worse by the Tax Reform Act of 1986, which made graduate student stipends taxable.

My colleague, Dr. Jules LaPidus, will address the tax reform impact in much greater detail.

Adding to the problems of decreased support for graduate study has been the sharply increased dependence on providing undergraduate student support in the form of loans rather than grants. One of the reasons graduating seniors now give for not going on to graduate study is the level of their accumulated debt by the time they have finished undergraduate work.

What is the role of the Federal Government? I believe the Federal Government should double the number of fellowships and traineeships, increase the support for research assistantships, provide increased incentives for underrepresented minorities and women to earn Ph.D.s, and providing funding to strengthen the overall research support environment at the universities.

We also need to expand the pipeline of students eligible to take doctoral studies, particularly in science and engineering, from increasing support for research opportunities for undergraduate students and improving the science and mathematics curricula at the elementary and high school level. A critical part of expanding the engineering and science pipeline rests upon understanding better why individuals undertake careers in science and engineering.

I am submitting for the record the 1988 American Association for the Advancement of Science Presidential Lecture by Sheila Widnall, which discusses how educational environments can promote or discourage participation in graduate work by women or underrepresented minorities. I can assure you that her insights have received widespread attention by faculty and administrators trying to improve institutional encouragement and support of graduate study.

I will close with some observations about the connections between research and graduate education. In our country's research universities, these two functions are inseparable. Both are performed by the same people in the same institutions, and both functions benefit from the interchange.

The opportunity for graduate students to conduct research with faculty working at the forefront of their fields provides the best education possible. Faculty investigators and their research programs, in turn, are continually renewed and enriched by the creative new ideas of the graduate students.

The declining number of U.S. students earning Ph.D.s and the declining number of those who do choose academic careers, reflects in large measure the increased pressures on the academic research environment. It is sometimes called the "hassle factor." Twenty years ago, the academic life offered the rewards of freedom for unfettered research and the opportunity to teach, to be enriched by working with bright graduate students and research carried out with state-of-the- art instrumentation and facilities.

Today much of that has changed. The Government appears to have abandoned its support of instrumentation and facilities, reduced its support for graduate education, and failed to keep pace with the rising cost of research in the project grant system. As a consequence, eminent university investigators are conducting research on increasingly outdated instrumentation housed in inadequate research facilities, and struggling to find sufficient support for their graduate students.

Graduate and undergraduate students see the struggles of the nation's top academic faculty researchers, and a serious disincentive to students considering an academic career has occurred.

In summary, the problem is urgent but solvable. The Federal role should support increasing fellowships, traineeships and assistantships, developing incentives for attracting women and underrepresented minorities into doctoral studies, providing funding to strengthen university research environments, and developing programs to expand the pipeline.

A more extensive description of the problems and recommendations for solutions are provided in a March 1989 draft AAU Policy Statement which I also submit for the record.

Thank you.

[The prepared statement of Dr. Liebman, plus attachments follow:]

STATEMENT
BEFORE THE
SUBCOMMITTEE ON SCIENCE, RESEARCH AND TECHNOLOGY
OF THE
COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
IN THE
U.S. HOUSE OF REPRESENTATIVES

HEARING ON STIMULATING INVESTMENT IN RESEARCH AND DEVELOPMENT

GIVEN BY

JUDITH S. LIEBMAN
Vice-Chancellor for Research and Dean of the Graduate College
University of Illinois at Urbana-Champaign

ON BEHALF OF THE

ASSOCIATION OF AMERICAN UNIVERSITIES
ASSOCIATION OF GRADUATE SCHOOLS

May 18, 1989

Thank you, Mr. Chairman, for providing the opportunity for me to speak at this hearing. As Vice-Chancellor for Research and Dean of the Graduate College at the University of Illinois at Urbana-Champaign, I am deeply concerned about the implications of the current demographic trends for doctoral education specifically, and for graduate education in general.

I. The Importance of Doctoral Education

Doctoral education has directly or indirectly benefited virtually every major scientific development of the last 30 years. Examples include the U.S. space program, the enormous potential of genetic engineering, the discovery of superconductivity, and the development of the computer technology now integrated into the fabric of our daily lives, from automobiles to VCR's.

Doctoral programs educate the scientists and engineers needed by industry, government, and universities for R&D activities. Furthermore, graduate students in doctoral programs are a key ingredient of university-based research; they conduct much of the research and generate many of the new ideas.[1]

The maintenance and growth of any modern society requires a special kind of intellectual nourishment, a continuing inflow of new ideas, discoveries, and technologies. Doctoral education trains the individuals who will generate and disseminate these new ideas and discoveries. Although an increased demand for Ph.D.s is predicted, the supply forecast is gloomy. Already there is a shortage of engineering faculty nationwide, and a shortfall of 7,500 natural science and engineering Ph.D.s annually is predicted shortly after the turn of the century.[2] Unless we take action now, we will not be able to sustain and increase our country's rate of technological and economic growth.

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[1] "The Federal Role in Doctoral Education," a policy statement of the Association of American Universities, DRAFT, March 30, 1989 (hereafter cited as AAU Federal Role statement).

The problem is exacerbated by growing employment opportunities for Ph.D.s in nonacademic settings, partly due to increased R&D efforts in the private sector. Also, growing awareness of the importance of international trade has generated demand for more graduates in foreign languages and international studies.

II. Demographic Trends

The college-age population will continue to drop until 1995 and then increase rapidly to above the current level by the year 2005.[3] At the same time this increase in potential student load is occurring, there is expected to be a decrease in the university faculties available to teach because many professors hired in the post-Sputnik expansion will be reaching retirement. Where are the replacement faculty to come from? Because of the length of time needed for graduate work, these replacements must come from students currently entering or enrolled in college. Thus the problem is urgent, and solutions must be implemented now.

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[2] AAU Federal Role statement

[3] AAU Federal Role statement

Additional demographic trends are of even more concern for science and engineering education. An increasing proportion of our working population are women and minorities, groups that have traditionally been underrepresented in the fields of science and engineering, two very important areas of graduate study.

The impact of these demographic trends upon doctoral degree recipients is already visible. The percentage of U.S. citizens receiving doctorates has decreased over the last decade, and this drop has been particularly severe in engineering. In 1970, 73% of the doctorates in engineering were awarded to U.S. students; by 1986, that percentage had dropped to less than 41%. The accomplishments and contributions of students from other countries have been and continue to be significant, particularly in science and engineering. But at most only about 70% of foreign degree recipients currently remain in the United States, and that percentage can be expected to drop as students' home countries increase incentives for them to return. We simply cannot afford to remain dependent upon a foreign supply of scientists and engineers to meet our research and development needs.

We must also consider the impact of the major science projects looming on the horizon, such as the SSC, sequencing of the human genome, the space station, and meeting the challenge of AIDS. All of these projects will need additional scientific manpower, over and above our continuing needs in education and normal R&D activities.

III. Increasing the Supply

How do we increase the number of graduate students? A continuing, dependable, and stable supply of fellowships, traineeships, and assistantships is the primary answer. It has worked before, and it will work again.

After World War II, the federal government played an active and successful role in the development and training of graduate students, through the sponsoring of fellowships, traineeships, and the funding of university research. Large-scale federal support for graduate education began in 1958 under the National Defense Education Act, followed by support programs established in federal agencies such as NSF and NIH. Under this expansion, the number of federally funded graduate student stipends rose from 1,600 in 1954 to 80,000 in 1969.

But there was a sudden decline in federal support, beginning in 1970. In a five-year period, "NDEA Title IV fellowships, NSF traineeships, NIH/NIMH fellowships, and NASA traineeships were eliminated; NSF fellowships and NIH/NIMH/ADMHA training grants were substantially reduced. Fellowship and traineeship support continued to decline into the 1980s."[4] We also lost doctoral student support under the GI Bill, which had supported almost 750,000 students in graduate programs in the twenty-year period following 1966.

This declining financial support has been exacerbated by the Tax Reform Act of 1986, which made graduate student stipends taxable. My colleague, Dr. Jules LaPidus, will address the tax reform impact in further detail.

Adding to the problem of decreased support for graduate study has been the sharply increased dependence on loans, rather than grants, at the undergraduate level. One of the reasons graduating seniors now give for not going on to graduate study is their accumulated debt by the time they finish undergraduate work.

What is the role of the federal government? Recommendations from the Association of American Universities[5] include:

- doubling the number of fellowships and traineeships
- increasing support for research assistantships through federal agencies supporting academic research
- providing increased incentives for underrepresented minorities and women to earn Ph.D.s

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[4] AAU Federal Role statement
[5] AAU Federal Role statement

- provide funding to strengthen the overall research support environment at universities

To meet the forecasted demand for scientists and engineers it will also be necessary to expand the pipeline of students eligible to undertake doctoral studies in science and engineering through:

- increasing support for research opportunities for undergraduate students
- improving the science and mathematics curricula at the elementary and high school level

A critical part of expanding the engineering and science pipeline rests upon understanding better why individuals undertake careers in science and engineering. To successfully encourage greater numbers of women and minorities to enter these fields, we need to develop effective intervention strategies at the appropriate points in their educational experiences. I submit, for the record, the 1988 AAAS Presidential Lecture by Sheila Widnall, which discusses how educational environments can promote or discourage participation in graduate work by women or minorities. I can assure you that her insights have received widespread attention by faculty and administrators trying to improve institutional encouragement and support of graduate study.

IV. The Interrelationship Between Graduate Education and Research

I will close with some observations about the close connection between research and graduate education. In our country's research universities, these two functions are almost inseparable, both performed by the same people in the same institutions; and both functions benefit from the interchange. The opportunity for bright young graduate students to conduct research with faculty working at the forefront of their fields provides the best education possible; faculty investigators and their research programs, in turn, are continually renewed and enriched by the creative new ideas of graduate students.

Because of this intimate interrelationship between graduate education and research, policies affecting one affect the other. I have focused this morning on programs providing direct support for graduate study. But the level and quality of support for research also has a powerful impact on the career decisions of graduate students.

I fear that the declining number of U.S. students earning Ph.D.s, and the declining number of Ph.D.s who choose academic careers, reflects in large measure the increased pressures on the academic research establishment. "Twenty years ago, academic research was operating vigorously at the frontiers of knowledge. The federal government had invested heavily in all aspects of the research enterprise, from support for faculty investigators and graduate students to support for institutions, research instrumentation, and facilities. . . [A]cademic research offered the rewards of . . . freedom of investigation and the opportunity to teach and to be enriched by working with bright young graduate students in research carried out with state-of-the-art instrumentation and facilities.

"Today, much of that has changed. The government abandoned its support of instrumentation and facilities, reduced its support of graduate education, and failed to keep pace with the rising cost of research in the project grant system. As a consequence, eminent university investigators are conducting research on increasingly outdated instrumentation housed in inadequate research facilities, juggling several project grants to sustain core research funding, and struggling to find sufficient support for their graduate students."[6]

The deterioration in the quality of the professional life of an academic scientist was a major concern discussed by Dr. Frank Press, President of the National Academy of Sciences, in his recent address to the Academy. Press cited the declining purchase power of research grants and the growing amount of time spent writing proposals, gaining approvals for projects, and managing grants; in one major institution, 100 scientists are writing 500 proposals each year to sustain their research.[7] Graduate and undergraduate students see this growing pressure on the nation's top academic faculty

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6. AAU Federal Role statement
7. "How to Run American Science (Successfully)," an address by Frank Press, President, National Academy of Sciences, presented at the 126th Annual Meeting of the National Academy of Sciences, April 25, 1989.

investigators; it is a serious disincentive to students considering an academic career. I will not go into detail on national research policy here but simply reemphasize the interconnections within our research and graduate education system and ask you to recognize that policies enhancing or detracting from one component of that system reverberate throughout the system.

V. Summary

In summary, the problem is urgent but solvable. The federal role involves increasing fellowships, traineeships, and assistantships, developing incentives for attracting women and underrepresented minorities into doctoral studies, providing funding to strengthen university research environments, and developing programs to expand the pipeline. A more extensive description of this problem and recommendations for solution are contained in a March 1989 draft AAU Policy statement, which I also submit for the record.[8]

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[8] AAU Federal Role statement

AAAS Presidential Lecture: Voices from the Pipeline

SHEILA E. WIDNALL

The number of white males of college age, who have been the dominant participants in the fields of science and engineering, is predicted to drop significantly in the future. Rapid increases in the participation of women offer some hope of filling anticipated vacancies in the ranks of scientifically trained personnel, although this rapid growth has reached a plateau in many fields. Most studies show that women enter graduate school at about the same rate as men; the dropoff in women's participation occurs sometime before the attainment of the Ph.D. Recent surveys of graduate students indicate that men and women respond differently to the pressures of graduate school and often have a different image of themselves and of their advisers' perceptions of them as graduate students. Some clues from these results may show how the environment can be made more supportive for all students, and for women and minority students in particular.

AS PRESIDENT OF AAAS I HAVE CHOSEN THE OPPORTUNITY of the presidential lecture to discuss an issue in which I have been involved since the early 1970s—during a time of rapid increases in the number of women studying for scientific and technical careers. I have been actively involved in encouraging women to enter such careers and in helping to reshape the institutions in which these women find themselves. The issue of the full participation of women in science is at the very heart of the question of who will do science in the years ahead.

Demographic trends predict a future significant drop in the numbers of white males of college age, who have been the dominant participants in science and engineering. The likely effects of these trends on scientific and engineering personnel have been documented by the National Science Foundation and the Office of Technology Assessment (OTA) of the U.S. Congress. If current participation rates continue, the future pool of science and engineering baccalaureates is projected to show a significant drop (*1–4*) (Fig. 1). We have now passed the peak of U.S. graduate students available from traditional pools and are headed down the slope to a 26% decrease in the pool by the late 1990s. What is hidden in these statistics is that the percentage of minority students in this age cohort will increase substantially. Since this group is currently underrepresented in science and engineering graduate programs, a projection based on the current participation of various groups would show even a more severe drop in the production of scientifically trained personnel at the Ph.D. level.

In addition, the percentage of B.S. degree holders in science and engineering who attain the Ph.D. degree has fallen from about 12 to 6% over the past 20 years (*1*). In engineering, the number of Ph.D.'s obtained by U.S. citizens per year fell by more than 50% between 1970 and 1986 (*5*), and at present more than 50% of Ph.D.'s in engineering awarded each year go to foreign nationals (*1*). In science, the actual number of Ph.D. degrees awarded to male U.S. citizens has continually tended downward since 1970 (*1*). Increased competition between industries and universities for the reduced number of B.S. degree holders will likely occur. Indeed, this competition is evident already in engineering and is a major reason for the significant decrease in U.S. students attaining the Ph.D. in engineering.

These issues have provoked a number of responses from the scientific and education communities. The importance of precollege science and mathematics education for all children, with special emphasis on disadvantaged groups, has been stressed. The possibilities of influencing career choice at various decision points have been discussed. The climate for B.S. students in science and engineering has received much attention, as has the issue of discrimination in the workplace and its effect on career choice. Projecting future work force needs and availability is difficult, since slight changes in the participation rates can cause large swings in the data. Nonetheless, on the basis of current information, the composition of the graduate school population can be expected to change dramatically over the next two decades.

One of the most important offsetting trends in the projection of rapid decreases in scientifically trained personnel has been the rapid increase in the participation of women across all fields of science and engineering (*2*) (Fig. 2). This trend offers some hope of filling anticipated vacancies in the ranks of scientifically trained personnel, although this rapid growth began to plateau in many fields after 1985. There has also been a correspondingly rapid increase in the percentage of women in law, medical, and graduate business schools: women now make up 40% of the students in law school and 34% of the students in medical schools, and they receive 31% of M.B.A. degrees (*2*).

An OTA report (*6*) presented the pipeline issues for women students in the natural sciences and engineering relative to that of men in a dramatic way (Fig. 3). The report described an initial

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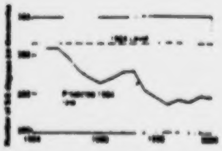
Fig. 1. Number (in thousands) of future science and engineering (S/E) baccalaureates, assuming 1984 participation rates (1).



cohort of 2000 male and 2000 female students at the ninth grade level. Of that original cohort, only 1000 of each group will have sufficient mathematics at the ninth grade level to remain in the pipeline. When the two groups are followed to the end of high school, 280 men and 220 women will have completed sufficient mathematics to pursue a technical career. A major drop in women students occurs with career choice upon entering college, with 140 men and 44 women choosing scientific careers. After a career choice is made, a larger percentage of women than men actually complete their intended degree in science and engineering: at the B.S. level, 46 men and 20 women receive degrees. Data show that women enter graduate school in the same proportion relative to their percentage of B.S. degrees as do men in the various technical specialties (7). (The number actually entering graduate school from each cohort is estimated from their current presence in graduate schools since entry data are not available.) However, some combination of attrition and stopping at the M.S. level rather than going on for the Ph.D. creates another major drop for the women students in the pipeline. Of the original 2000 students in each group, five men and one woman will receive the Ph.D. degree in some field of the natural sciences or engineering.

These results suggest that two points of concentration on the career aspirations of women students would be fruitful: at the initial career choice and during the graduate school years. Many studies and projects have been carried out on the point of early career choice; much less has been documented about the environment in graduate school and its effect on degree completion rates.

Beyond the issue of the health of the scientific enterprise and the necessity to make full use of the intellectual talents of all of our population, there is the issue of equality of opportunity for these talented individuals. In addition, we should concern ourselves with the issue of future public support for science on the part of groups who perceive that they have been excluded from full participation in the scientific enterprise. The years ahead may be troublesome for the support of science, and the image of science as a community accessible to all will be important to maintain public support.

Graduate Student Surveys

Several recent surveys of male and female graduate students preparing for scientific and technical careers were carried out at Stanford University (8) and at the Massachusetts Institute of Technology (MIT) (9, 10). In addition to quantitative detail about differential attitudes, expectations, and experiences of these students, the wealth of comments from students provides considerable insight about the process of graduate education as seen from the student's perspective.

In the Stanford study, graduate students in medicine, science, and engineering were surveyed, with a 54% return rate for a total number of 627 students. The results were presented only for the combined group. The major conclusions of this work were that the

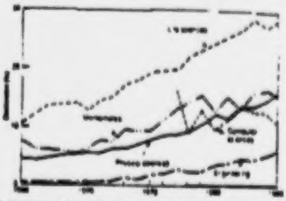


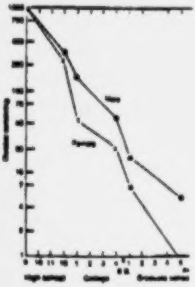
Fig. 2. Percentage of natural science and engineering doctorates awarded to women. [Source: National Science Foundation and National Rese Council, Washington, D.C.]

women were indistinguishable from the men in objective measu of preparation, career aspirations, and performance in gradu school. They differed significantly in their perceptions of th preparation for graduate study, in the pressures and roadblocks t they experienced, and in the strategies that they developed coping with these pressures.

Graduate students at MIT were surveyed both by the Gradu School Council (9) and by the presidentially appointed Commit on Women Students Interests (10). Both surveys covered all of departments in the institute. More than 1600 questionnaires in tute-wide were returned in the first survey. Within the School Science, 476 student questionnaires were returned in the seco survey. The MIT surveys reinforced the conclusions of the Stanf survey. In addition, in both of the MIT surveys, the results diffe widely across departments, including responses to questions focu on the academic environment for women students. Whether th distinctions are due to differences in fields, the different percent of women students in the various departments, the personality the departments, or specific policies and practices that a departm uses to provide information and academic guidance to the stude is not clear. However, the survey results indicate that for depa ments with a poor environment for women students, a few spec measures might lead to considerable improvement for all studen

Nationally, women enter graduate school at about the same r

Fig. 3. Cohort remaining in the pipeline at various stages in the educational process in the fields of natural science and engineering from an initial group of 2000 ninth grade girls and 2000 ninth grade boys. Attrition estimates derived from OTA data (6).



as even relative to their presence at the B.S. point (8). The career aspirations of women in the Stanford survey were the same as those of the men. Objective measures of their academic achievements and potential indicate that the entering women students were as qualified for graduate work as the men. Men in the Stanford survey scored slightly higher on the math section of the Graduate Record Examination, whereas women scored higher on both the verbal and the analytical portions of the exam and had a higher undergraduate grade point average. The grade point averages of the male and female students in graduate students were essentially the same (8). As a group representative of only a fractional percentage of the cohort of females of their age, statistics of large groups or preconceived ideas about their specific interests, attitudes, aptitudes, or competencies cannot be applied.

The drop-off in women's participation in scientific careers after the B.S. degree seems to coincide with the lower rate of attainment of the Ph.D. I have been unable to identify comprehensive studies of attrition from graduate school in science and engineering, but available data suggest that women often stop at the M.S. degree rather than continuing to the Ph.D. and that many more women report serious consideration of dropping out of graduate programs. Anecdotal information suggests that they do drop out at a higher rate than the men. Also, data indicate that a larger percentage of women students is to some extent self-supporting (8). Within a given field, there is a direct correlation between male-female differentials in self-support and differentials in the time required to attain the Ph.D. degree. [The disparity in self-support is even greater for blacks (8)].

Graduate Education and Research

Education can be seen as a continuum, a progression from the development of career-related skills in a preset curriculum to the achievement of autonomous professional capabilities. However, it is at the graduate level that the student begins to function as an independent scientist—indeed, that is the purpose of graduate education. Ideally, graduate education should proceed from an explicit set of tasks—acquiring advanced skills through courses, preparing for and passing a set of qualifying exams to demonstrate mastery of one's field, and carrying out technical work under the close supervision of a faculty adviser—to the development of independence in the student. During this process the faculty gradually begins to remove the props supporting the student and to place more responsibility on the student for problem formulation, evaluation, execution, and defense. Ideally, as the process occurs, the student has access to a variety of structured professional experiences designed to enhance self-confidence and build independence. These experiences include opportunities to present and defend research results in regular and productive group meetings, to evaluate and criticize the work of peers, to formulate and carry out research tasks of increasing importance, to participate in dialogues and debates about scientific and technical issues, and to discuss future career plans as they relate to current interests and activities.

Faculty members often do not make these latter parts of the educational process explicit to the student. Much of the stress of graduate education results from a lack of student understanding of this hidden agenda. Students who duck such professional experiences because of a lack of self-confidence or because they find them painful are deprived of an important component of the graduate experience. Although they may be successful in achieving a Ph.D., they may not be equipped to take full advantage of the next set of career possibilities, and they are unlikely to be recommended by their mentors for important opportunities in their profession. Attention to how women and minorities are affected by and respond to this hidden agenda will be valuable in developing strategies to allow them to achieve their full potential.

To be successful, the graduate student must run both an academic and a financial support gauntlet. The academic gauntlet is the most explicit. Successful passing of graduate-level courses and various exams by specified deadlines are usually clearly laid out as requirements for the students. Less clear is the issue of financial support, the desirability of various forms, and the leverage that certain modes of financial support give to the success of these research and adviser interactions. The task for the student is to find a spot in a functioning research group, work on a topic central to the interests of the group with sufficient financial resources to carry out the research, and work with a faculty adviser who will both supervise the research and guide the educational and future career development of the student. The level of support required for this task is well beyond what is needed to support the student's living expenses.

A fellowship, while providing some flexibility in the beginning of a graduate program, may actually delay the acceptance of the student as a member of a research group. A teaching assistantship, while providing financial support and interaction with younger students, can also delay acceptance into a research group and offer less time for carrying out independent research. The research assistantship (RA) will facilitate the student's acceptance into a research group, provide a research topic central to the group, and allow access to resources such as equipment and computer time. The fact that a smaller percentage of women graduate students than men in all fields of science are supported on RAs (8) has serious implications for the quality of their graduate education.

Whatever goals the student had when the initial decision to attend graduate school was made, the process itself will continually act to reformulate these goals. The continual testing and trial of one's academic and personal characteristics, the ongoing interaction with peers and supervisors, and the signals picked up about one's relative potential within the research group will reshape the career goals and

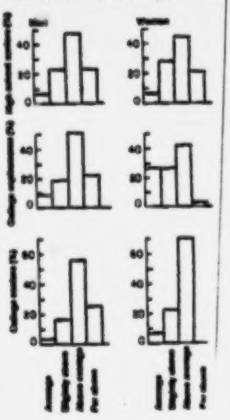


Fig. 4. Self-report of intelligence as compared to peers (11).

affect the research productivity and career aspirations of the students. The research opportunities presented by the faculty and the quality of interaction and support will strongly determine the quality of graduate education and the preparation for further career advancement. A reasonable objective for the education of women and minority students is that they have a fair chance to succeed in graduate school; that the feedback loop of lowered expectations based on sex or race, leading to lowered self-image and finally to lower performance, be broken by conscious action by faculty and students; and that the students be aware of the future consequences of career-related decisions.

Because the Ph.D. thesis is primarily an apprenticeship in research, the success of the graduate experience depends on the quality of interaction with the adviser. The adviser is the primary gatekeeper for the professional self-esteem of the student, the rate of progress toward the degree, and access to future opportunities. Problems with the adviser-student relationship are apt to go unreported by the student out of fear of professional reprisals. There are few checks and balances in the system, and the rest of the department faculty can do little to redirect an impaired relationship. Changing advisers after investing several years in research is a traumatic experience for the student, and it is likely to delay receipt of the degree considerably.

Our current method of financing scientific research and graduate education puts considerable stress on both faculty and students. The graduate students are the first in line to be affected by pass-through stress from their research supervisors. The continued search for research funds and the continued high level of professional activity required to remain at the forefront of research make faculty less accessible to students. The graduate education process is labor-intensive, requiring large amounts of faculty time. Students are often aware only of breakdowns in the system: the neglect of the faculty, their inaccessibility, their failure to appear at oral exams, and their occasional unprepared lectures. The current system of support of graduate education makes it impossible for a faculty member to make a commitment of support to the student for the length of a typical graduate program. Gaps in funding are common, and students are often faced with the choice of dropping out or taking on a debt burden to complete their degree.

These familiar facts of life of graduate education are at the heart of much of the stress felt by all graduate students. However, the white male students benefit from the self-reinforcing confidence that "they belong." The self-identification with the predominantly white male faculty reassures them that graduate school is a step on the way to a productive career in science, and that many others with whom they can identify have done it before them. For women students, minority students, and many foreign students, the environment is not as reinforcing. Their acceptance by the system is not automatic. Results from the Stanford survey (*8*) indicate that 38% of the men compared to 24% of the women were confident of "making it" in their chosen field; 62% of the men, but only 51% of the women, anticipated an academic career.

Results from Student Surveys

In the various student surveys, students commented on their personal experiences in graduate school. Most of the comments were complaints about the current system. There were subtle differences in the responses of men and women. The men most often expressed anger, even rage, at the system and suggested ways that it should be changed, whereas the women more often described the effect that the current system had on them and expressed feelings of frustration and discouragement. For example, the following comments were made by students from the same department when asked what hindered their graduate education (*10*):

1) From a man: "The absolute insensitivity of the professor, department, and university to the inevitable depression experience by young scientists when their research doesn't work so wel The . . . university's . . . willingness to ignore all graduate students but the . . . top 10% elite."

2) From a woman: "Despite denials, as a woman in . . . science . . . I had something to prove—and yet the most difficult par about it is that I don't know what it is or how to prove it. There just the knowledge that I have at least one more test to pass than m male counterparts. Or maybe it's one more test to pass daily."

As revealed by student surveys, the issues affecting minority foreign, and women students are related to their differences from th majority, their feelings of powerlessness, and feelings of increase pressure and isolation. For example, significantly larger percentage of women students than men students in both the Stanford and th MIT studies reported that the environment was detrimental to thei health (*8*, *10*). In the Stanford survey, 23% of the women versus 9 of the men reported that they thought they were on the verge of nervous breakdown. The data on minority students are too sparse t draw any conclusions, but it is likely that graduate school is a extremely stressful environment for them.

Women students are not a minority at the undergraduate level i our colleges and universities. Yet the effect that education has o them sets the stage for their minority presence in graduate schoo Studies indicate that the self-esteem of women students is lowered i college, while the self-esteem of male students is raised.

The Illinois Valedictorian Project (*11*) was a study that followed group of 80 students (46 women and 34 men) who had graduate in 1981 at the top of their high school classes. The group continue their high academic performance, with the women earning a firs grade point average of 3.6 and the men an average of 3.5 for the college years. In spite of this objective record, when this group wa surveyed at several points in their educational careers concernin their self-estimates of intelligence relative to their peers, the resul shown in Fig. 4 were obtained. The shift of self-esteem to lowe ratings is quite evident for the women students. At the end of hig school the groups were quite comparable, but females suffered significant loss of self-esteem in the sophomore year of college. A the senior year of college, no women had a self-estimate in th highest category, whereas 25% of the men did, even though th grade point average of the women was higher than that of the me In contrast, the self-esteem of the men increased slightly during th college years. Even though women in science have degree completion rates above those of the men and carry on to graduate school a about the same rate, these results suggest that they arrive at graduat school with some uncertainty about their abilities, even though the academic records and test scores are equivalent to those of the men

A second trend noted in this study (*11*) was the lowering of care ambitions by the women students. The researchers linked lowere career ambitions in part to the unresolved dual-career problem: th is, the student's uncertainty about how to combine career and fami responsibilities. One of the most effective antidotes for the uncertainties about career goals was the opportunity for successf professional experiences: independent research, professional employment, opportunity for interaction with graduate students, o the support and encouragement of a faculty mentor. Most wome scientists of my generation can probably point to a single individu who was supportive at the undergraduate level without who encouragement they would not have gone to graduate school.

Without such opportunities a woman student may carry throug with excellent performance in classes but be unsure about her tru potential as a professional. She may also develop the well-doc mented "impostor" syndrome with its accompanying fear of ally being "found out." This insecurity shows up in several ways. In spite of objective data indicating that women in graduate school have academic backgrounds comparable to their male peers, a significantly higher percentage of women in the Stanford survey (*8*) reported that their preparation for graduate school was inadequate. In the MIT survey (*10*), women students reported more difficulty in acquiring research skills. Whether these self-assessment reports are true or represent women students who downgrade their capabilities is not clear from the data. The reports could also be related to the student's interactions with her research adviser. In some cases the process of acquiring research skills may be unconsciously set up for women to fail: women may be given too much help on easy skill-building problems (because it is perceived that they cannot do the work alone) and then are left to flounder on the more difficult problems. In the Stanford survey, 82% of the men and 71% of the women reported being satisfied with their programs. 72% of the men and 61% of the women reported that they believed they were progressing as well as other students (*8*).

For the women students themselves, as well as the departments in which they study, some serious attention to these issues is warranted. Objective discussions between adviser and student about the academic background required to undertake certain lines of research should take place, and ways to fill in any weak areas should be identified. Discussions of the expectations of the department for graduate student performance beyond the classroom, identification of objective criteria that should be met on the way to independent research, and some specific attention to methods of acquiring research skills are suggestions to deal with these issues.

Studies of objective evaluations of the potential and the accomplishments of women give quite discouraging results. Such studies in which male or female names are applied to résumés, proposals, and papers that are then evaluated by both male and female evaluators consistently show that the potential and accomplishments of women are undervalued by both men and women, relative to the same documents with a male attribution (*12-15*). I believe that graduate admissions officers are aware of this and attempt to correct for it in the admissions process, but I would be surprised if individual, hard-pressed faculty were immune from this behavior.

Lower expectations by an adviser, whether conscious or unconscious, are quickly perceived by the student. This perception may occur more often with women students, who need additional feedback because of their tenuous position. The student surveys show that women meet less frequently with their research advisers; a smaller percentage of women than men meet weekly, a larger percentage of women than men report meeting rarely with their advisers. Also, more women report that these interactions with faculty do not provide helpful feedback on their research progress. There seem to be qualitative differences in the type of feedback that some women students are looking for. To quote one woman from the MIT survey (*10*): "My adviser tells me whether it's right, not whether it's important." Women reported less frequently than men that they felt free to disagree with their advisers or that their ideas were respected by their advisers (*8*). The issue of barriers to effective communication needs to be examined by both advisers and their women students.

Many faculty socialize extensively with their graduate students through sports and informal get-togethers and may unintentionally leave out their women students or even suggest that they are unwelcome at such gatherings. Women students often conclude that this is a direct reflection of the quality of their research (*10*). Perceived lowered expectations lead directly to a loss of self-esteem and over time to a lower performance—a self-fulfilling prophecy. Women students give their advisers a great deal of power in assessing their ability, and women are apt to internalize and validate their perceptions of this assessment.

On all of the questions in the Stanford survey designed to elicit the level of self-confidence in the academic setting, the women students scored consistently, and in some cases alarmingly, lower than the men: 30% of the women versus 15% of the men questioned their ability to handle the work; 37 versus 12% found criticism difficult to accept; only 30% of the women versus 57% of the men felt confident speaking up in class; and 33 versus 9% feared that speaking up would reveal their inadequacies (*8*). In view of the importance of the hidden agenda that uses structured professional experiences to elicit independence in the student, some significant fraction of the women students is less equipped to seek out, to engage, and to profit from these experiences. Explicit attention to structuring positive professional experiences for all graduate students will improve the environment for women students.

In the Stanford survey, more women (20%) than men (6%) reported never having had major responsibilities within their research group (*8*). In both the Stanford and MIT surveys, women reported less opportunity to publish, or less frequently being the first author on publications (*8, 10*). However, these results differed across departments, with the most encouraging results obtained in those departments that had high percentages of women students.

Environmental Issues

Women graduate students report being subject to inappropriate treatment by faculty and student colleagues. Inappropriate treatment in the context of graduate school is any treatment that emphasizes the student as a woman first and a student second. It is any treatment that stresses the social nature of the interaction rather than the professional or educational nature (*13-16*). Many women students report the necessity to continually fend off such inappropriate behavior in order to be allowed to concentrate on the professional issues of graduate school. This continual need to respond to such treatment can seriously interfere with the self-esteem and productivity of women graduate students (*15*).

Even today, there are still a few faculty members in science and engineering who publicly, or in discussions with faculty colleagues, take the position that women do not belong in graduate school. These individuals are at the least tolerated and seldom publicly challenged by their colleagues. Female graduate students quickly become aware of such feelings; although such actions cannot be attributed to an entire department, one wonders how such behavior can be tolerated in a university environment. It is particularly unfortunate if the individual involved would otherwise be the most appropriate adviser for the student on the basis of the student's research area.

Studies of group meetings involving men and women reveal that women are at a disadvantage with respect to male peers in groups (*13-16*). Women are interrupted by men much more frequently than are other men. A woman's contributions are often ignored or attributed to one of the men in the group. Many women students report discomfort at the combative style of communication within their research groups. Studies of men and women in group situations reveal differences in their styles of communication and reaction in their interpersonal interactions (*13-16*). Men often feel comfortable with a communication style that seeks to reduce one of the protagonists to rubble in the context of a scientific discussion. After the storm is over, they quickly forget about the incident. For many women this style of interaction is unacceptable, either as giver or receiver. A woman student may take weeks or months to recover from such an interchange, and it may contribute to a permanent loss of self-esteem. Women report that a process in which points are won only at the expense of putting someone else down is to them an unacceptable mode of scientific debate. They are looking for a mode of interaction that is other than a zero-sum game.

Women students report being much less satisfied with the information available from departmental channels on issues such as the structure of qualifying exams and financial support policies. They also report not being as well integrated into the student network (where copies of past exams, for example, can be obtained). For access to such resources, the acceptance of women students as colleagues by their male peers is essential.

A disturbing percentage of women in the MIT survey reported that their gender is a significant barrier to access to academic resources (*10*). The quantitative results ranged from 16 to 30% across the various departments in the School of Science. This was true even in those departments where women students had high self-esteem. In the Stanford survey, 12% of the women (compared to 1% of the men) reported that the sex of their adviser had a negative impact on them; 40% of the women (compared with 30% of the men) reported having had some negative experience with faculty members, whereas 20% of the women (versus 7% of the men) reported experiencing some form of discrimination (*8*).

Women students have raised some fundamental issues about the quality of graduate education for all students. The continued drop-off in the percentage of B.S. degree holders who eventually attain the Ph.D. may be related directly to the current environment seen by graduate students. If we are to escape the projected dramatic decrease in the number of graduate students, some improvement in graduate education for all students is necessary.

With respect to improving the environment for women students, an increased sensitivity on the part of faculty to the seriousness of women as professionals and the willingness of faculty to structure the research environment to enhance self-esteem and provide positive professional experiences are the most important features. A willingness by the faculty to publicly challenge professional colleagues who make prejudicial or inappropriate remarks about women students would improve the climate. An effort by faculty to make the group interaction a positive-sum game for all students, while being no less insightful and scientifically critical, would enhance the graduate experience. The positive comments on the student surveys by both men and women reported the beneficial effects of such an educational environment. Such suggestions, if more widely followed, would improve the professional and human climate of our graduate schools for all students.

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DRAFT

THE FEDERAL ROLE IN DOCTORAL EDUCATION

A POLICY STATEMENT
OF THE
ASSOCIATION OF AMERICAN UNIVERSITIES

March 30, 1989

OVERVIEW

Doctoral education produces the scientists, teachers, and scholars responsible for the discovery and dissemination of new knowledge and the preservation and interpretation of our intellectual and cultural heritage. Doctoral education is critical to our national security, international competitiveness, and the health of our citizens and the quality of their lives.

Since World War II, the federal government has looked to research universities as the nation's primary source of basic research and research training. Federal support for faculty investigators, graduate students, facilities and instrumentation played a key role in the development of America's interdependent system of university research and graduate education, which is acknowledged worldwide for its quality and productivity.

That system is about to be severely stressed. Beginning in the mid-1990s, increased faculty vacancies and increased undergraduate enrollments will combine with a growing demand for Ph.D.s in nonacademic markets to increase sharply the need for doctorate recipients. The Ph.D.s that will be needed should be entering graduate school now.

But supply is moving in the opposite direction of demand. The percentage of U.S. citizens receiving doctorates has declined for over a decade. Non-Asian minorities and women remain severely underrepresented in graduate education. The deterioration of the academic research environment discourages talented students from pursuing academic careers. Under current trends, the nation will suffer an annual shortfall of 7,500 science and engineering Ph.D.s just a few years into the next century. Shortages of nonscience Ph.D.s will occur as well. The impact of such shortages will affect industry, government, and colleges and universities, all of which depend on doctoral education.

Prompt action must be taken by all patrons of graduate education–government, foundations, industry, and universities. The federal role should be to provide increased incentives for talented U.S. students to enroll in doctoral programs and to assist universities in restoring the quality of the academic research environment. The federal government should take the following actions:

- double the number of fellowships and traineeships
- increase support for research assistantships through federal agencies supporting academic research
- provide increased incentives for underrepresented minorities and women to earn Ph.D.s
- restore a comprehensive investment in university research by providing expanded, flexible support for research and direct funding for research facilities and instrumentation.

When U.S. preeminence in science and technology was challenged in 1957 by the launching of Sputnik, the federal government responded with sharply increased funding for graduate education and research. The response succeeded, increasing both the size and quality of university research and graduate education programs.

Thirty years later, a similar effort is required. A recent report by the White House Science Council on the health of U.S. colleges and universities concluded that "our universities today simply cannot respond to society's expectation for them or discharge their national responsibilities in research and education without substantially increased support." [1] The cost of federal action to strengthen U.S. doctoral education will be far less than the cost to the nation of a failure to act.

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1. Office of Science and Technology Policy, Executive Office of the President. *Report of the White House Science Council Panel on the Health of U.S. Colleges and Universities*. Washington, D.C.: 1986.

THE FEDERAL ROLE IN DOCTORAL EDUCATION

The United States invested an estimated $132 billion in R&D in FY 1989, and for good reason: R&D is critical to national security, industrial growth, advances in health care, and the application of new knowledge in virtually every facet of our society.

R&D could not occur without doctoral education. Doctoral programs educate the scientists and engineers needed by industry, government, and universities. In addition, the students in those programs are a key ingredient of *current* research: they are active research performers, conducting a large portion of university research and enriching it with new ideas. To a greater extent than in other countries, U.S. graduate students are major determinants of the creativity and productivity of university research, the source of more than 50% of the nation's basic research. It is the depth of this graduate student involvement that makes the U.S. research establishment unique.

The United States has built the largest, most accessible higher education system in the world. More than 50% of American high school graduates enroll in higher education programs. In 1988, over 12 million students attended U.S. colleges and universities. These institutions employ over 700,000 faculty. Two-thirds of them hold doctorate degrees. Through their dual role in the discovery and dissemination of knowledge, doctorate faculty continually advance the knowledge students acquire.

The reach of doctoral education extends beyond the university. In 1985 an estimated 43% of all Ph.D.s employed in this country were working outside of higher education.[2] The demand for doctorate recipients in nonacademic sectors is growing; an increasing number of Ph.D.s in all areas–physical sciences, engineering, life sciences, social sciences, and humanities–are employed outside academia. *[Figure 1–Ph.D. Employment]* Fifty percent of 1987 doctorate recipients had employment commitments outside academia.[3]

Doctoral education has played a key role in virtually every major scientific and cultural event of the last 30 years. The U.S. space program, the enormous potential of genetic engineering, the discovery of superconductivity, the elimination of major diseases, the green revolution in agriculture, books that have changed people's lives and illuminated public debates on cultural values and national goals, the enrichment of the life of the mind through teaching and scholarship–all have benefited from doctoral education. So, too, will doctoral education play a pivotal role in progress on the challenges that now confront us in environmental pollution, the maintenance of national security amid shifting balances of power, and the yet unidentified problems generated by an expanding human population competing for diminishing resources.

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[2] Bowen, Howard R. and Schuster, Jack H. *American Professors–A National Resource Imperiled*. New York: Oxford University Press, 1986.

[3] *Summary Report 1987*, National Research Council (p. 25)

Viewed from a different perspective, the nation's doctoral education enterprise carries out an awesome responsibility through a comparatively small and delicate system. In 1986, 31,843 doctoral degrees were awarded, scarcely 3% of the 987,823 bachelor's degrees granted in that year. Although well over 400 institutions offer at least one doctorate-granting program, 60 universities provided more than 60% of all doctorates granted over the decade between 1977 and 1986. This country's programs of doctoral education are widely and rightly regarded as among the finest in the world; the benefits of that quality reach broadly through our society.

THE HEALTH OF DOCTORAL EDUCATION

In many respects, the doctoral education enterprise appears to be healthy. By most accounts, the quality of students entering doctoral programs is as high as it has ever been. In the context of shifting college populations and labor markets, the number of Ph.D.s awarded has remained remarkably stable for a decade. Employment of doctorate recipients remains higher than that of any other sector of higher education.

However, the stability and quality of U.S. doctoral education is about to be severely challenged. Beginning in the mid-1990s, an increased rate of faculty departures will collide with increased demand for teaching faculty. An increase in faculty vacancies will occur as large numbers of professors hired during the post-Sputnik faculty expansion reach retirement age. The size of the 18- to 22-year-old cohort, which has been declining, will reverse in the late 1990s and increase through the first decade of the 21st century, producing increased college enrollments. *[Figure 2–Shifting College-age Population]*. An expansion of faculty will have to be part of the response to the increased teaching load.

The sharp increase in demand for faculty will be superimposed on a growing demand for Ph.D.s in nonacademic markets. The competitiveness of the U.S. economy will be subjected to increasing pressure by other nations in the years ahead. Our strongest competitors–Japan and the countries of Western Europe–are expanding their investments in science and technology, recognizing the importance of these functions to economic productivity. *[Figure 3–R&D Expenditures by the U.S. and Its Economic Competitors] [Figure 4–International Comparisons of Science and Engineering Employment]*

Responding to these challenges will increase demand for scientists and engineers. The enactment in 1992 of the Common Market pact to eliminate trade barriers will add to the competitive pressure on U.S. trade with England and Western Europe. This will be only one of the factors pressing American business to operate more effectively through the languages and customs of its overseas markets, requiring expanded capacity in language and area studies.

Major science projects also will increase the demand for science and engineering Ph.D.s, both within universities and within government. The Superconducting

Supercollider, mapping the human genome, and the space station will open new pathways to discovery. Other challenges, such as AIDS and the threat of global warming, confront us now. The scientists and engineers needed to carry out these projects represent *added* personnel requirements; they cannot be drawn from the existing workforce without diminishing our current R&D effort.

Are current policies adequate to meet increasing demand? There is clear and compelling evidence that the answer is no. Three trends are working against the capacity of universities to meet an increased demand for doctorate recipients: (1) the declining number of Ph.D.s earned by U.S. citizens, (2) the continued underrepresentation of non-Asian minorities and women, and (3) the deterioration of the academic research environment.

Declining U.S. Doctorates

Although the number of doctorates awarded has remained stable for the last decade, the number of U.S. citizens receiving doctorates has declined steadily, offset by increased numbers of foreign Ph.D.s. In 1970, 84.5% of doctorate recipients were U.S. citizens, 8.7% were foreign students with temporary visas, and the remainder were foreign students with permanent visas.[4] By 1986, the percentage of U.S. citizens receiving doctorates had dropped to 72.3%, while the percentage of foreign students with temporary visas receiving doctorates doubled to 16.6%. *[Figure 5–Declining Proportion of U.S. Citizens Earning Ph.D.s]*

The shift from U.S. to foreign students has been even greater in science and engineering fields. In the physical sciences, U.S. doctorate recipients dropped from 82.2% in 1970 to 62.5% in 1986; in engineering, the drop was from 73.2% to 40.8%.

That so many foreign students are enrolling in U.S. graduate programs testifies to the quality of those programs. The infusion of talented students from other nations strengthens our doctoral programs and enriches this country's intellectual resources. But it is unwise national policy to rely so heavily on imported talent and fail to develop our own intellectual resources. The Korean and Chinese governments have begun systematically calling back their Ph.D.s educated here; other countries can be expected to institute similar policies as their environments for research and scholarship improve.

The frequently expressed concern that the best students are opting for careers in business or the professions is not quite accurate: some of our best students continue to pursue doctorate degrees, but not enough of them.

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[4] The distinction between foreign students holding temporary visas and those holding permanent visas is important, since the latter are far more likely to have postdoctoral employment commitments in this country (National Research Council, *Summary Report 1986* [pgs. 5-7]).

Underrepresentation of Minorities and Women

Between the late 1950s and early 1970s, the size of the graduate education enterprise grew rapidly. During that period, participation in doctoral programs by underrepresented groups--non-Asian minorities and women--increased as well. The increases of several of these groups have not been sustained or have been followed by actual declines. It is not clear what accounts for changes in participation rates. Participation in doctoral programs by all male groups except Asians decreased between 1977 and 1986. The number of black male doctorate recipients dropped most sharply, from 684 to 321; white male doctorate recipients dropped from 17,011 to 12,257. Participation in doctoral programs by all female groups increased over the same period; however, these increases occurred early in this period and appear to have leveled off in the 1980s.

In 1987, 7[illegible] blacks earned Ph.D.s, 4.5% of total Ph.D.s awarded. Since blacks make up roughly 12[illegible] of the population, they are underrepresented in education by nearly a factor of three. Hispanics, who make up 6.5% of the population, received 2.8% of 1987 Ph.D.s. Underrepresentation of women and minorities is particularly severe in the physical sciences and engineering. Blacks received less than 1% of the Ph.D.s awarded to U.S. citizens in the physical sciences and engineering in 1987. Women earned over 35% of total Ph.D.s but only 6.5% of engineering Ph.D.s awarded that year.

The underrepresentation in doctoral education of minorities and women must be addressed both as a matter of practical necessity and of social justice. We cannot accept the costs of a continued inability to recruit the talent from the half of the population which is female and from minority groups, which are among the fastest growing sectors of our society. And we must question the equality of educational opportunity for groups persistently underrepresented at the highest levels of our educational system.

Deterioration of the Academic Research Environment

Twenty years ago, academic research was operating vigorously at the frontiers of knowledge. The federal government had invested heavily in all aspects of the research enterprise, from support for faculty investigators and graduate students to support for institutions, research instrumentation, and facilities. In comparison to industrial research, academic research offered the rewards of greater freedom of investigation and the opportunity to teach and to be enriched by working with bright young graduate students in research carried out with state-of-the-art instrumentation and facilities.

Today, much of that has changed. The government abandoned its support of instrumentation and facilities, reduced its support of graduate education, and failed to keep pace with the rising cost of research in the project grant system. As a consequence, eminent university investigators are conducting research on increasingly outdated instrumentation housed in inadequate research facilities, juggling several project grants to sustain core research funding, and struggling to find sufficient support for their graduate students. In contrast, top industrial research laboratories provide excellent infrastructure support and provide their leading researchers with sustained funding and considerable freedom to explore their own research interests.

With such a contrast before them, it is not surprising that many science and engineering college graduates choose to embark on a career in industry–and begin earning a high salary immediately–rather than choose subsistence support during extended years of doctoral education followed by an increasingly arduous and unrewarding academic career.

A Time for Action

Supply and demand are moving in opposite directions in doctoral education. A recent analysis has shown that current trends will result in an *annual* shortfall of 7,500 science and engineering Ph.D.s just a few years into the next century.[5] Increased faculty vacancies and college enrollments will combine with expanded nonacademic markets for Ph.D.s in humanities and related fields to produce a shortfall in nonscience fields as well.

Absent concerted action, universities, government, and industry will soon be pitted against each other in an intensified competition that will ill-serve the nation no matter who wins. Teachers will be found for college classes, but the quality of that teaching and of the programs of research and scholarship conducted by the nation's faculty will be severely strained. Diminution of the quality of university teaching and research will reverberate through the entire system which draws on doctoral education. At a time of mounting challenges, foreign and domestic, the nation cannot afford such an outcome.

The increased number of Ph.D.s the nation will require should be entering graduate school now. Those increased graduate enrollments must be drawn from a shrinking pool of college graduates *[see Figure 2]*. Any market response will occur too late and will be limited and unbalanced.

What actions need to be taken to empower the doctoral education enterprise to meet these challenges? Who must assume the responsibility to carry out those actions? The remaining sections of the paper describe overall support for doctoral education, examine the special role of the federal government, and present recommendations for strengthening that role.

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[5] Atkinson, Richard C. "Supply and Demand for Science and Engineering Ph.D.s: A National Crisis in the Making." Remarks to the Regents of the University of California, February 16, 1989.

WHO PAYS FOR DOCTORAL EDUCATION?

Doctoral education benefits a number of sectors of society, and a number of patrons support the enterprise. Federal and state governments, industry, private foundations, and universities provide financial assistance for graduate study *[Table 1–Financial Aid for Graduate Education]*.

Students make the greatest commitment to doctoral education. Over 42% of doctorate recipients report self-support as their *primary* form of financial support.[6] All doctoral students bear a less tangible but larger cost in time and foregone income. It now takes over 10 years after receipt of a bachelor's degree to earn a doctorate degree; the median age of doctorate recipients is 33.6 years *[Table 2 –Time-to-Degree]*. That is a decade of time during which doctoral students sacrifice immediate career options and earned income.

Institutions provide the largest share of financial assistance to doctoral students, over 52% in 1987. Such support is provided primarily as teaching assistantships and institutional fellowships. Universities recognize the value of balanced, high-quality doctoral programs. Graduate students extend the teaching capacity of university faculty effectively and economically. Because they are so deeply involved in research, exceptional graduate students provide universities with a powerful attraction in recruiting a strong faculty.

Foundations support doctoral programs in accordance with their philanthropic goals. Twenty years ago, foundations played a key role in the build-up of the current university system of language and area studies centers. Several foundations today are supporting programs designed to fill gaps in graduate support. Notable among these are the Mellon Fellowships in the Humanities and the programs of several foundations designed to increase the number of students from underrepresented minority groups who receive doctorate degrees.

Industry has a direct interest in doctoral education, particularly in science and engineering. Individual corporations and industrial consortia support a number of graduate fellowship programs designed to attract students into fields of interest to them. Ironically, industry provides a strong disincentive to enroll in graduate education by hiring science and engineering college graduates at salaries which make graduate education an almost irrational economic choice. Much has been written about the problem of industry "eating its seed corn." Industry recognizes a long-term interest in encouraging a larger portion of students to pursue doctoral education to provide the teaching faculty upon which industry depends. That recognition is not likely to produce a significant expansion of graduate support, however. Shifts in corporate policies toward greater long-term investments are not imminent, particularly where the return on investment to any specific corporation is necessarily indirect and uncertain.

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[6] *Summary Report 1986*, National Research Council.

States support doctoral education primarily through their support of resident public universities. A number of states recently have developed programs to enhance local science and technology capacity; expanded support for graduate education frequently is a component of such programs. Because the benefits of doctoral education are primarily national in scope, states, like industrial sponsors, are likely to remain constrained by the limited linkage between investment in doctoral education and local returns.

FEDERAL ROLE IN DOCTORAL EDUCATION

It remains for the federal government to lead the effort to prevent a costly divergence of supply and demand. Only the federal government has the capacity to marshall the resources required for an effective national response. Only the federal government has a scope of responsibilities spanning the full range of functions dependent on doctoral education.

Leadership in science and technology is a national imperative, and doctoral education is an essential component of our scientific and technological capacity. Preserving our heritage; applying the lessons of the past to present problems; encouraging the creativity of our citizens; assuring that we are the masters, not the servants, of our science and technology--these activities are the domain of teaching, research, and scholarship in the humanities and in the arts. They are national imperatives, and their support falls squarely within the province of the federal government.

The federal government has a strong, vested interest in doctoral education. It has the tools to advance that interest. What are the appropriate mechanisms for federal action? An examination of the history of federal support and the adequacy of current programs provide a clear framework for strengthening federal policy.

History of Federal Support for Doctoral Education

Federal support for university research increased rapidly during and after World War II, but not until the launching of Sputnik in 1957 did the government begin substantial funding of graduate education.

Large-scale federal support for graduate study was initiated with the passage of the National Defense Education Act in 1958. Over its 14-year life, NDEA Title IV supported nearly 46,000 graduate students. Additional fellowship and traineeship programs were established in NIH, NSF, NASA, and other federal agencies. Combined with support through research assistantships, the number of federally funded graduate student stipends increased from 1,600 in 1954 to approximately 80,000 in 1969.

The growth in federal support was accompanied by a comparable growth in the size of the enterprise: doctorate recipients increased from just under 10,000 in 1960 to over 26,000 in 1969.

The period of growth in federal programs was followed by a precipitous decline. Between 1970 and 1975, NDEA Title IV fellowships, NSF traineeships, NIH/NIMH fellowships, and NASA traineeships were eliminated; NSF fellowships and NIH/NIMH/ADAMHA training grants were substantially reduced. Fellowship and traineeship support continued to decline into the 1980s.

In the sciences, the decline in federal support was partially offset by an increase in research assistantships, from 21,400 in 1974 to 35,000 in 1986. Federal support for graduate study in the humanities and social sciences fared comparatively poorly throughout the period of growth as well as decline: little support outside NDEA Title IV was available to these disciplines during the growth period, and they lacked the buffer of research assistantships during the decline.

Compounding the loss of support due to the elimination of fellowships and traineeships, the support provided by remaining programs has been reduced by the Tax Reform Act of 1986, which made stipends taxable.

The GI Bill has also been lost to doctoral students. Between 1966 and 1986, the GI Bill supported 748,112 students in graduate programs. The demise of the post-Korean GI Bill was a major loss of educational support at both the undergraduate and graduate levels. However, the loss of undergraduate financial support was offset at least in part by the enactment of major new student financial aid programs. At the graduate level, the loss the GI bill simply dovetailed with the elimination of fellowship and traineeship programs.

Current Federal Support

In FY 1989, the federal government is spending a little over $200 million to support roughly 12,000 graduate students through fellowships and traineeships *[Table 3–FY'89 Federal Support]*. Including an estimated 35,000 research assistantships, federally funded stipends total 47,000, an almost twofold decrease from the peak number of 80,000 in 1969. Federal support for graduate education as a proportion of overall federal support for academic research declined from ___ in 1969 to ___ in 1986. The correlation between eroding federal support and declining numbers of U.S. Ph.D.s is difficult to dismiss.

The federal government has taken several steps to expand investment in research and research infrastructure. Since 1980, support through NSF for instrumentation has increased from 6% to 18% of its research expenditures. Both the Bush and Reagan Administrations have proposed a doubling of the NSF research budget over five years. In FY 1989, Congress authorized an NSF research facilities program providing real hope of the first systematic investment in facilities by the federal government since the early

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1970s. These are indeed encouraging trends, but much remains to be done. Congress has yet to appropriate funds for the new facilities program, the annual targets for doubling the NSF research budget have been missed in each of the first two years of that proposal, and other federal agencies have generally not matched NSF's support of research instrumentation.

A FEDERAL RESPONSE TO INCREASED DEMAND FOR PH.D.S

To meet the need for increased doctorate recipients, federal policy must address the declining number of U.S. students receiving Ph.D.s, the underrepresentation in doctoral education of non-Asian minorities and women, and the deterioration of the academic research environment. The history of federal support shows that national policy can have a profound and beneficial impact on the size and composition of the enterprise. An attempt to scale precisely the dimensions of that effect, however, is likely to fail because of the inherent imprecision of both demographic projections and manpower programs.

The soundest approach is to focus on quality through a federal policy providing increased incentives for the nation's most talented college graduates to enroll in doctoral programs and actions to restore the quality of the academic research environment. Many of the components of such a policy are already in place; what is needed is to strengthen existing programs and fill certain gaps to produce a stable, balanced support system. The capacity of the federal government to respond is limited by its budget deficit. Nonetheless, federal policymakers should act to the fullest extent permitted within their budgetary constraints.

Federal policy should be organized around the following four components:

- Fellowships and traineeships
- Research assistantships
- Support for minorities and women
- Restoring the academic research environment

1. *Fellowships and Traineeships*

Those federal agencies with a direct stake in graduate education should support strong fellowship or traineeship programs appropriate to their missions. Studies of the comparative performance of students supported under such programs show that they finish their degrees more quickly and are more likely to receive research grant support than students of comparable ability lacking such support.

Fellowships are grants awarded directly to students by the granting agency. Traineeships are block grants awarded to institutions or departments; departments use grant funds to provide traineeship support to students they select. In both types of grant program, four characteristics are critical to program success:

- selection of recipients based on merit
- the provision of multiyear support
- stipends sufficient to attract exceptionally talented students
- payment of tuition and fees or an institutional allowance that meets a reasonable proportion of the actual institutional costs to educate a doctoral student.

The allocation of grant support based on merit assures that funds are directed to the best students and programs. Multiyear support providing a reasonable living allowance enhances the recruitment value of the grants, provides stability of support for a substantial part of the doctoral program, and provides students with the freedom to pursue the educational program that is optimal for them. Payment of tuition and fees or an institutional allowance frees students of a substantial financial burden and assists institutions in meeting educational costs.

Most federal agencies with a clear interest in graduate education already support some form of fellowship or traineeship program. Thus, the basic structure of an effective matrix of programs is in place. The costs to complete that matrix are not large. The following actions need to be taken:

Double the number of fellowships and traineeships.

When the U.S. needed rapidly to strengthen its research and graduate education capacity following the launching of Sputnik, fellowship and traineeship programs were established to increase the number of U.S. citizens earning Ph.D.s. The programs quickly accomplished this objective.

The nation requires an increase in graduate enrollments by U.S. students again. Doubling the number of fellowships and traineeships will provide such an increase.

The doubling of federal fellowships and traineeships should include the following:

- Complete NSF's proposed doubling of its graduate fellowship programs from 570 to 1140 new awards annually.

- Increase the number of NIH traineeships to meet the targets established by the National Academy of Sciences.

- Expand the number of fellowships and traineeships supported by the other major research-funding agencies. DOD, DOE, NASA, and USDA have well-designed and well-administered programs, but they are small in comparison to the volume of university research supported by those agencies. *[Table 4–Agency/Academic R&D Obligations]*

- Increase fellowship support for graduate study in the humanities and related fields in two ways: (1) expand the Department of Education's Javits Fellowship program, the sole federal program supporting graduate study in the arts and humanities, and one of the few programs supporting graduate study in the social sciences; (2) establish a graduate fellowship program in the National Endowment for the Humanities.

Increase the length of time and level of financial support provided by existing programs and fill program gaps:

- Stipends should provide an adequate living allowance. Several existing programs do not meet that test, including NIH traineeships (although the NIH moved a welcome step in that direction with an increase of the predoctoral stipend for FY'89) and the Department of Education's Foreign Language and Area Studies (FLAS) fellowships.

- Institutional allowances should meet a reasonable proportion of the actual institutional costs of education, increasing with increases in those costs.

- The Department's FLAS fellowships provide an average of only two years of support in fields in which the time required to earn a doctorate is over eight years. The recently authorized advanced graduate fellowships for language and area studies students should be funded to fill this gap.

- The National Endowment for the Humanities should establish a dissertation fellowship program. Unlike science and engineering students, humanities graduate students do not have access to research assistantships to provide support during their dissertation research. Support from teaching assistantships or fellowships has generally been used up by students at the dissertation stage. A national competition in which dissertation proposals are judged on the merits of the proposed research could be administered through the Endowment's existing mechanisms for funding faculty research fellowships.

2. *Research Assistantships*

Agencies supporting university research should promote the support of graduate students as research assistants. The target should be at least one research assistant per grant. Inclusion of graduate students as research assistants not only provides effective apprenticeship training but enhances the quality of the research itself by providing fresh perspectives.

Federal research agencies vary widely in the extent to which their research project grant programs support graduate research assistants. *[Table 5–Pending]* Concern has been expressed in the graduate community that pressure, real or perceived, to limit the size of grant requests to increase their likelihood of approval is discouraging faculty investigators from including research assistants on their grants. However, in FY 1988, NSF supported 15,833 graduate students on 15,647 research project grants. NSF's target for FY 1990 is to support 19,309 RAs on 17,894 project grants. Other agencies should adopt similar policies tailored to their research programs.

Congress should provide NEH with the statutory authority to support research assistantships. Although the opportunities for such support are more limited in the humanities than in science and engineering fields, the Endowment does support a number of major, multiyear research projects in which research assistantship support would provide cost-effective research support while assisting in the education of future scholars. Research assistantships also would provide an additional mechanism for supporting dissertation work.

3. *Support for Women and Minorities*

The underrepresentation in doctoral education of non-Asian minorities and women must be addressed by all sectors supporting graduate education. Several private foundations have focused on this problem. Institutions are aggressively pursuing new and expanded recruitment and retention programs. These efforts are producing results. At one university, the sustained involvement of faculty advocates in the recruitment and admissions process has produced a doubling of minority graduate students admitted in one year. At another institution, a systematic retention program has produced an 87% completion rate for minority doctoral students.[7]

The federal government funds a number of programs aimed at increasing the participation of minorities in graduate education. The National Science Foundation is proposing a new program of fellowships for women in engineering. The following steps will enhance the federal government's commitment:

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[7] These institutional programs are expensive. They require added faculty time for individual monitoring and advising. They require additional courses and seminars tailored to individual needs. The high cost of such institutional intervention and support for individual students limits their implementation by institutions.

- Expand the number and scope of minority graduate fellowship programs. The Department of Education, NSF, NIH, and NASA are among the federal agencies with strong minority fellowship programs, but some agencies provide little or no support for minority students.

- Agencies which fund research in fields such as engineering in which women are severely underrepresented should develop programs to attract women into these fields.

- Each research funding agency should adopt a program of project grant supplementation for supporting minority research assistants. Such a program would be separate from the primary grant application and funding process, permitting project investigators to add minority RAs to their research program whenever the opportunity arises. An administratively simple program providing incremental funding for minority RAs would provide a strong incentive for faculty investigators to seek opportunities to engage minority graduate students as research assistants.

- Increase the number of early identification programs for talented minority undergraduate and high school students. The NIH Minority Access to Research Careers program (MARC) is a highly successful program providing summer research internships for minority undergraduates; a similar program has recently begun through the Department of Education. Such programs should be carried out through each agency supporting graduate education.

- Provide institutional matching grants for recruitment and retention programs–both to develop and to replicate successful initiatives. Such grants would allow institutions to expand their internal efforts significantly.

These actions are directed primarily at the undergraduate pool from which graduate students will be recruited. But particularly in the case of minority students, underrepresentation is traceable to disadvantages accumulating from the beginnings of the educational pipeline; intervention must begin well before students reach the college level. Agencies such as the Department of Education, NSF, and NEH should explore new ways to work with local and state school authorities to provide talented minority children with the kinds of enriched educational experiences that promote academic opportunity and excellence.

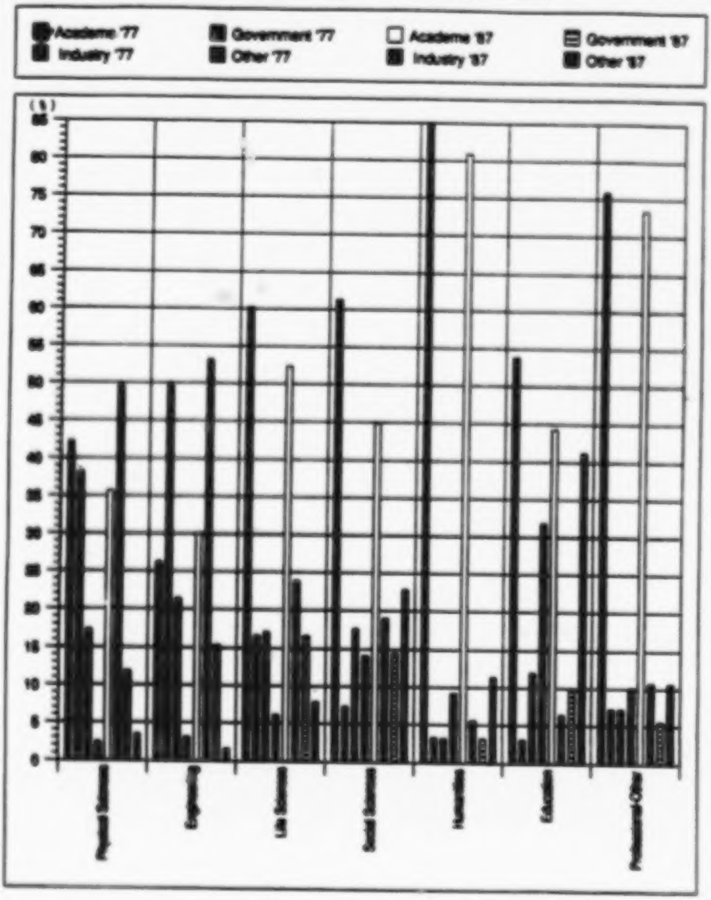
4. *Restoring the academic research environment*

Increased research funding, combined with greater stability in its allocation and greater flexibility in its use, will do much to restore the quality of the academic research environment. In addition, the federal government should restore its former commitment to the support of research infrastructure. In 1987, the White House Science Council called for a $500-million-per-year, 10-year effort as a "necessary minimum" response to restore the nation's deteriorating academic research facilities. To implement this effort, programs such as the recently authorized NSF facilities program should be authorized and funded to the extent possible in each of the major federal agencies supporting academic research. In addition, the Department of Education's Title VII facilities programs should be funded.

CONCLUSION

The federal government must play a central role in strengthening support for doctoral education to provide the increased number of Ph.D.s that will be needed soon in both academic and nonacademic sectors. The mechanisms of federal support are largely in place. Strengthening existing programs and filling gaps in support can effectively increase the incentives for talented students to enroll in doctoral programs. Action now can curtail the divergence of supply and demand and develop more fully our intellectual resources to meet the challenges of the 21st century.

Figure 1 - Employment Commitments of Ph.D.s



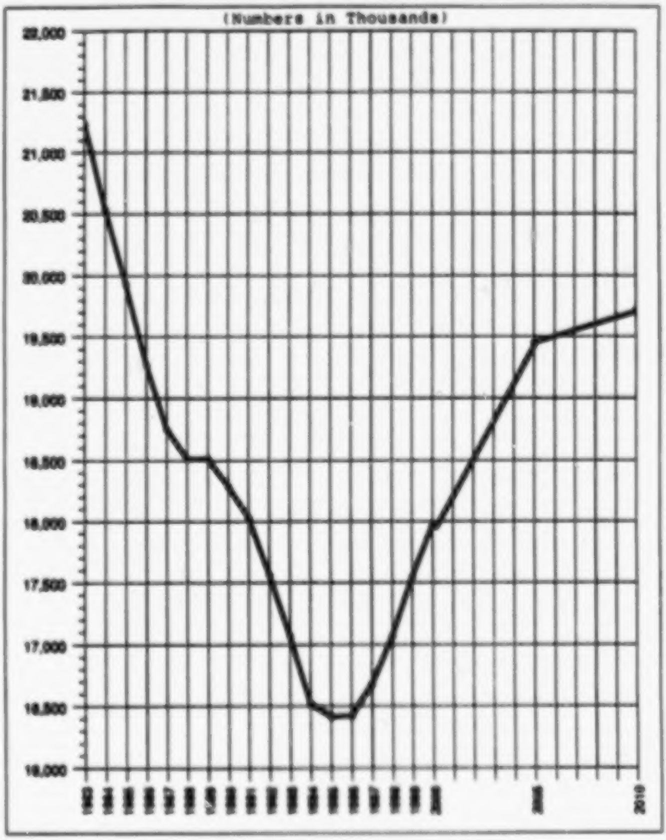


Figure 2 - Shifting College-Age Population

Figure 3: R&D Expenditures by the U.S. and its Economic Competitors

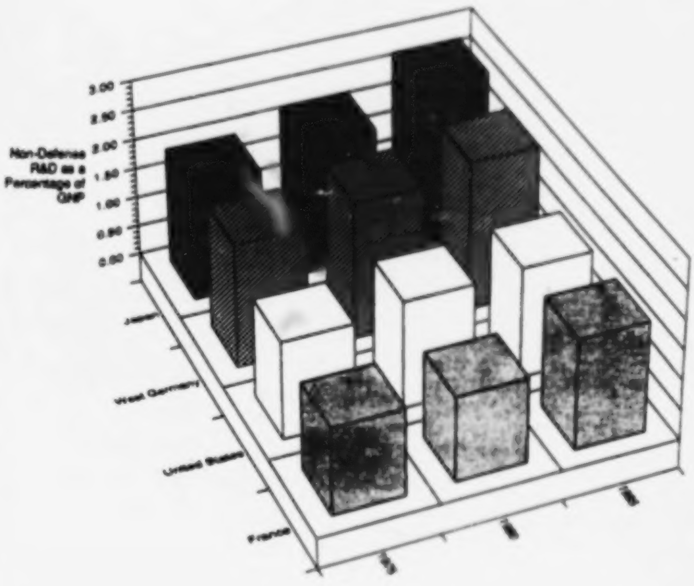


Figure 4: International Comparisons of Science and Engineering Employment

(S/E's in R&D per 10,000 labor force population)

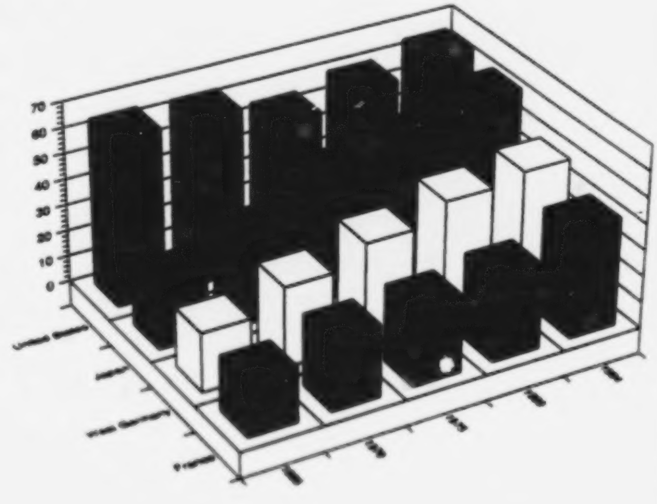
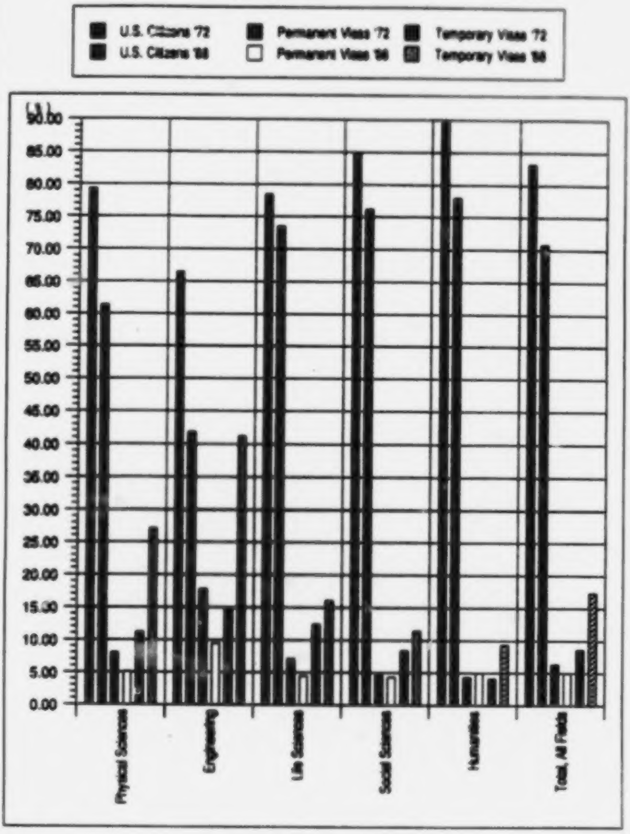


Figure 5 - Declining Proportion of U.S. Citizens Earning Ph.D.s



Financial Aid for Grad. Ed.

	1987 $ (millions)	1987 %	1973 $ (millions)	1973 %
Federal	**900**	**42.40**	**345**	**43.20**
Fellowships/Traineeships	200	8.60	150	18.80
Research Assistantships	525	25.00	130	16.30
Loans	125	6.00	20	2.50
College Work Study	20	1.00	5	0.60
GI Bill/Other Service Related Benefits	30	1.40	40	5.00
State	**45**	**2.10**	**10**	**1.20**
Grants	20	1.00	5	0.60
Loans	25	1.20	5	0.60
Institutional	**1,110**	**52.40**	**415**	**51.80**
Assistantships	850	40.50	350	43.70
Fellowships/Waivers	250	11.90	60	7.50
Loans	10	0.50	5	0.60
Private Sources	**65**	**3.10**	**30**	**3.80**
Employer Paid Benefits	25	1.20	10	1.30
Fellowships	30	1.40	15	1.90
Loans	10	0.50	5	0.60
Total Assistance	***2,120***	***100.00***	***800.00***	***100.00***

TABLE 1

Time-to-Degree

	1967	1977	1987
		(Years)	
Total			
Registered	5.40	6.10	6.90
Total	8.10	8.70	10.40
Physical Sciences			
Registered	5.10	5.70	6.00
Total	6.00	6.90	
Engineering			
Registered	5.20	5.60	5.80
Total	7.20	7.30	8.10
Life Sciences			
Registered	5.40	5.70	6.50
Total	7.20	7.30	8.70
Social Sciences			
Registered	5.20	5.90	7.20
Total	7.70	8.00	10.30
Humanities			
Registered	5.50	7.10	8.40
Total	8.40	9.90	12.00

TABLE 2

FY93 Federal Support

PROGRAM	TOTAL STUDENTS	TOTAL $
NSF	2,188	38,000,000
NRSA	5,000	92,300,000
NDSEG	150	3,150,000
AF	75	2,100,000
ONR	140	4,000,000
NASA	245	4,410,000
USDA	175	2,800,000
DOE	80	2,080,000
ED: Pub Service	215	3,320,000
ED: Harris	1,008	15,700,000
ED: Javits	570	7,900,000
ED: Nat'l Need	800	12,800,000
ED: FLAS	700	7,550,000
ED: Fulbright-Hays	90	1,500,000
USIA	500	10,000,000
TOTALS	11,937	$207,610,000

TABLE 3

Agency/Academic R&D Obligation

FY 1988

Agency	Total Obligation (in millions of $)	Fellowships/Traineeships (in millions of $)	Proportion of Obligatic Fellowships/Traineeship
USDA	277.1	4.7	1.70%
DOD	1149.7	0.5	0.04%
DOE	348.9	0.6	0.17%
HHS	3212.1	204.3	6.36%
NASA	254	4.5	1.77%
NSF	983.9	25.2	2.56%

Source: Federal Support to Universities, Colleges, and selected nonprofit Institutions; Fiscal Year 1988

TABLE 4

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Mr. **Hayes**. Thank you very much.

Congressman Walgren has exited to go vote so he can return and take the chair over upon his return and try not to postpone the hearing too long. Within a couple of minutes, though, Congresswoman Schneider and I will have to approve or disapprove the journal for yesterday. You'll find out that much like within academia, most people disagree with what we did yesterday as well as what we'll do tomorrow. I would like to, because of that, perhaps, interrupt and see if we can ask you a few questions during this transition before going directly into the testimony.

I am most concerned because what you're telling me I've heard at just about every hearing we've had in any subject in America. In Des Moines, Iowa I've listened to university professors and department heads tell me about drain of talent in the sciences. I've heard them tell me about historic dependence upon foreign students—which they say in the same manner in which you do, and unfortunately sometimes it isn't reported accurately—that this is not a criticism of bright young people throughout the world who seek educational opportunity here. This is a recognition that that dependence is not everlasting and that the historic relationship among those who stay in this country to contribute, as do so many bright young people from throughout the world, is not something we can count on for future decades. And, the second point that they make is that we don't seem to inspire our young people to pursue the sciences. It is not a matter of closing any of our doors, but a matter of, quite often a lack of excitement that's generated among those who go into other fields of endeavor. And you've added a third point—that we have also removed many of the opportunities that Government historically was able to give, in a full recognition that we want to encourage certain kinds of actions. Consequently, the suggestions that you have made along the line of what Government can do in light of tax considerations and additional funding I can certainly understand and wholeheartedly support.

I would like to pursue the other point for a moment. What can any of us do, whether it is as parents, as Government officials or as educators, about that third element I named—that is the incentives among people to have an interest in a career in so many fields of the sciences?

Dr. **Liebman**. When parents respond positively when their children show curiosity about how things work, when parents and school boards make sure that there are competent science and mathematics teachers in the elementary and secondary schools, that's going to make a big difference.

I think part of the confounding problem with what's going on, not only in the universities, but in the elementary and secondary school systems, is that salaries are low. Traditionally, teaching was a field which very bright young women entered. Now bright young women have many other opportunities, and the quality of the teaching we see has dropped.

Mr. **Hayes**. Additionally, we've had an opportunity to go with a very fine man who was the Congressional liaison for NASA, a former astronaut, and time after time when we would go to small high schools, we would find that the science teacher was a teacher taking over the science classes as an additional burden, rather than a primary field of endeavor.

Is this a subsequent generational impact of not having additional students going through our universities who in turn are teaching the sciences—are we now seeing the erosion of the educational base because of the previous two decades of dropping our number of graduates who in turn are teaching sciences?

Dr. **LIEBMAN**. Absolutely. A teacher who has taken over another class to teach science who has no innate love for science, is not going to be able to instill in his or her students the love of science and investigation that was before.

Mr. **HAYES**. I apologize to you, but in order to make this work, I'm going to ask that we suspend the hearing for just a few moments, and as soon as Congressman Walgren returns, I'm sure he'll take the chair and begin again. Doctor, I apologize to you, although when you come to visit South Louisiana, I'll be sure to change your name again so you'll be recognized. Thank you.

[Recess.]

Mr. **WALGREN** [ASSUMING CHAIR]. Gentlemen and gentlewomen, let me call you back to order and we'll proceed. I want to ask unanimous consent that the statement of Congressman Costello be inserted at the appropriate place in the record.

[The prepared statement of Mr. Costello follows:]

OPENING STATEMENT
BY U.S. REP. JERRY COSTELLO
COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
MAY 18, 1989
"INVESTMENT IN RESEARCH AND DEVELOPMENT"

First let me thank Dr. Judith Liebman, Vice Chancelor for Research at the University of Illinois, for being able to testify at today's hearing. The University of Illinois plays a critical role in providing research and development for the entire state, and their leadership in this area should be commended.

Research and development are two key areas to international competitiveness, and the focus for technological advancement. If our economy is to lead the world in new ideas and new products, we must have be at the forefront of the field, and the only way to do this is through increased research and development.

Studies show that American funding for research and development is well below that of our international competitors. As the chairman has pointed out, between 1970 and 1987 there actually was an 8 percent decrease in the number of patents awarded to U.S. inventors, while patents awarded to foreigners increased by almost 30 percent. This is indicative that our country's competitiveness is at stake.

I look forward to today's hearing and hearing the policies that will encourage research and development in the private sector.

Mr. WALGREN. We will continue with Dr. LaPidus' statement.

STATEMENT OF JULES LAPIDUS, PRESIDENT, COUNCIL OF GRADUATE SCHOOLS, WASHINGTON, D.C.

Dr. LAPIDUS. Thank you, Mr. Chairman. It's a pleasure to be here this morning. I am president of the Council of Graduate Schools, which is an organization of 388 universities that grant the vast majority of graduate degrees in the United States, roughly 95 percent of the doctoral degrees and about two-thirds of the masters degrees.

We, like you, are concerned about the scientific and technological future of the United States, and a great part of that concern has to do with Americans going on to graduate school in science and engineering. If we are to be competitive in the kind of world economy that exists, it is imperative that more Americans become scientifically and technologically literate, and that more go on to careers in research.

Unfortunately, as Dr. Liebman has pointed out, just the opposite is occurring. The number of American students going on to graduate school in science and engineering is declining and has been for some time.

The demographics of the graduate population are fairly complex. We don't understand all the reasons for this, but we do understand some of the things that influence students when they try to make choices about going to graduate school.

I think it's fairly clear that students who are qualified for graduate school understand that there are lots of other things they can do to make more money. The current starting salaries for scientists and engineers holding a baccalaureate degree in 1989 ranges between $25,000 and $35,000 a year.

Students considering graduate school find out fairly quickly that assistantships and fellowships provide stipends at a range from about $7,000 to $10,000 a year with some of the very prestigious national competitive fellowships going up to about $15,000 a year.

Since it takes about five to seven years to get a Ph.D. in these fields, it doesn't take much calculation to show that the foregone income for students taking this step is at least $100,000. But students have been willing to do this, providing they can get some support to go to graduate school.

One of the important things to keep in mind is that graduate stipends have never been developed to be competitive with industrial salaries. That really isn't the point. The purpose of graduate stipends is to provide enough support for students to live on, so that they can go to graduate school, and do research full time.

That being the case, there are probably three major factors involved when considering the kinds of support necessary to accomplish this. One is that it has to be available. Probably the best kind of support to have available is fellowship support. One of the reasons for that is that the next factor has to do with some kind of assurance of continuity. Students considering this long haul of arduous and demanding work like to feel that there is some assurance that they are going to be supported for more than one year.

Finally, the dollar amount of the awards that students seek has to be enough so that they can live during this period of time.

We've seen this happen in the United States before, as Dr. Liebman has pointed out. During the 1950s and 1960s, a marvelous program of Federal support developed for science, engineering and graduate education in general, and it worked. Lots of students went to school, and there was a tremendous outpouring of science and technology from this country.

Unfortunately, while we have been reaping the benefits of this investment, the rest of the world has been catching up, and we seem to have been going about the process of decreasing our commitment. The number of fellowships has declined dramatically, and the Tax Reform Act of 1986 also decreased our commitment in this area.

Prior to 1986, fellowships and most assistantships were not taxed. That goes back about 30 years. The Tax Reform Act of 1986 changed that so that the stipends, and by that I mean the money that students use to live on, room and board and other living expenses, the stipends are now taxed. The amount of that tax, and the level of decrease of a stipend, depends of course on the stipend itself and on the tax category of the student. But for the most part it amounts to about 14 percent, considering that most graduate students are in that category. What that means very simply is that a $10,000 stipend a couple of years ago is now a $8,600 stipend.

Associated with this reduction in stipends is the fact that certain kinds of tuition awards and waivers that are considered compensation, particularly, in return for services such as teaching, are also now taxable. The end result of this is that the tax code, which until now had been seen as being supportive of higher education, now seems to be operating in the other direction.

This is an unfortunate trend and I think we need to look at alternatives. If we are serious about increasing the commitment in this country to the future of science and technology and our competitiveness, and if we are serious about attracting more students to go to graduate school in these areas, clearly the way to do this is not by decreasing the number of fellowships available and decreasing the dollar value of those fellowships.

I think a much wiser approach would be to do what we have done in the past, that is to invest in this country's young people. There are a number of ways to do this, but one of them clearly is the kind of plan of well-constructed incentives that Dr. Liebman has mentioned, including traineeships, fellowships, assistantships and support for the research community.

This committee, historically, has been a strong advocate for these approaches, and we urge you to continue that and furthermore, to make it clear to your colleagues on appropriations and revenue committees that the task of providing adequate support for this nation's cadre of scientists and engineers is far from over.

Thank you. I'll be pleased to respond to any questions.

[The prepared statement of Dr. LaPidus follows:]

TESTIMONY

PRESENTED BEFORE THE
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON SCIENCE, RESEARCH, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

ON INCENTIVES THAT STIMULATE INTEREST AND INVESTMENT IN RESEARCH AND DEVELOPMENT

BY
JULES B. LAPIDUS
PRESIDENT
COUNCIL OF GRADUATE SCHOOLS
ONE DUPONT CIRCLE, N.W.
SUITE 430
WASHINGTON, D.C. 20035

MAY 18, 1989

Mr. Chairman and Members of the Subcommittee:

My name is Jules LaPidus, and I am the President of the Council of Graduate Schools. The Council of Graduate Schools has 388 member institutions around the country and represents the vast majority of producers of graduate degrees in the United States. Prior to assuming my CGS office, I was Dean of the Graduate School and Vice Provost for Research at the Ohio State University and a professor of medicinal chemistry for twenty-six years at OSU. I am pleased to be with you and the other members of the Subcommittee here this morning and would ask your permission that my written remarks become a part of the record of this hearing.

The charge of this hearing accurately reflects the concern that many of us have with producing an adequate supply of scientists and engineers. U.S. college students are graduating with increasing amounts of debt and many of us are concerned today that they will not choose the long and relatively costly route of obtaining advanced degrees in science and engineering. I am not completely convinced that we understand the cause and effect of the situation that exists on campus today. Some individuals clearly love learning for its own sake, and will pursue it regardless of cost, rewards, or benefits. Nevertheless, living within this society increasingly requires that individuals take into account the overall context in which they work and the overall sense of salaries and the market economy in which we all exist.

I want to briefly discuss the incentives we provide for students to go to graduate school, particularly in terms of fellowships and the impact of recent changes in the tax code on the size of graduate fellowships and assistantships. Fellowships and traineeships provide an ideal way to pursue graduate degrees in science and engineering. They provide assurance that support will be available for some multi-year period of full-time study in the area of science and engineering of interest to the student. Students can go through the process of learning to be independent scholars and researchers, receive a Ph.D., and move out into universities, industry, or the government, fully certified and capable of making a life-time contribution to the discovery of new knowledge and to teaching other individuals whether in the workplace or in the classroom. Regretfully, at the moment, there are relatively few such awards available. In 1989, the entire federal government is providing only 12,000 such awards. Few of them, with the exception of those funded by the Department of Defense, are as generous in their support as are the fellowships offered by the National Science Foundation ($13,100 stipend plus a $6,000 tuition allowance). Except in quantitative areas, such as the social sciences supported by NSF, there is almost no similar federal support available in the social sciences and the arts and humanities, with the exception of a small fellowship program supported by the Department of Education which is significant and which is the only major support for the arts, humanities, and social sciences.

The decline in the number of fellowships has created a serious problem. The Tax Reform Act of 1986 made it worse in several ways. In the period of years between 1954 and 1986, fellowships and most assistantships provided to graduate students working full-time on degrees were not taxed. Students received stipends to provide a living allowance and tuition scholarships or waivers to pay for tuition. The Tax Reform Act of 1986 reversed 25 years of favorable tax policy and made living allowances taxable, thus decreasing the value of these allowances by whatever the tax rate of the individual student might be, usually 14%. The 1986 Act also taxed that portion of the tuition award or tuition remission that was received as compensation for services. It did all of this in a convoluted way, focussing, as tax policies generally do, on the mass of population which includes the 12 million undergraduate students, most of whom were assumed to have little if any tax liability and thus would not be affected in any major way by such a policy change. In that respect, the tax writing committees, the Ways and Means Committee of the House of Representatives and the Senate Finance Committee, were absolutely correct. Unfortunately, for the 1.4 million graduate and professional students of whom perhaps 500,000 are engaged in full-time pursuit of a doctorate degree, there were significant differences and there were significant new tax liabilities, particularly for those students who had a working spouse or who, like most graduate students, received teaching or research assistantships. Congress did recognize this and proposed a technical amendment in the Technical and Miscellaneous Revenue Act of 1988, to the effect that tuition reductions in excess of reasonable compensation for teaching or research are excludable from income. Our office had literally hundreds of phone calls from students, faculty members, and institutions around the country to try to clarify the situation, and we are grateful for the support of the Congress over the last two years in reaching this clarification.

The 1968 Tax Act proved that strange offspring can issue from the marriage of tax reform and education policies. Advocates of tax reform argued that in fairness to individuals who pay for their education with after tax dollars it should discontinue the practice of tax-free scholarships. The education community argued that the very purpose of a scholarship was to subsidize and provide a benefit to a worthy individual and subjecting scholarships to tax clearly defeated this very important societal goal. The Committee decided to split the difference in a decision which did violence to both sides. It allowed tuition scholarships to remain untaxed while taxing payments for room and board. In a further twist, it subjected to tax, tuition waivers provided to graduate teaching and research assistance based upon the value of the services they provided. These changes are part of an unfortunate trend, in which the Tax Code, which once favored education, now heavily burdens it. The cutbacks and periodic expiration of Section 127, Employer Provided Education Assistance, and the increasing tax burden born by scholarship recipients, particularly graduate scholarship recipients, is an unfortunate turn of events. We find this somewhat puzzling given the strong support for continuation of the research and development tax credit. We support the credit and want to see it extended and so does a powerful coalition of high tech businesses. We would hope, however, that Congress also recognizes the importance of higher education , particularly graduate education, in our efforts to remain competitive in the world, and that the Congress consider reversing its recent unwise decision in the area of taxation of scholarships and graduate tuition waivers.

But Congress was determined to create a new kind of structure with fewer instances of specialized treatment of both business and individuals and this was perhaps a necessary sacrifice towards that end. Nevertheless, this is one more example of a situation that has created an additional impediment for students considering full-time graduate study.

The other long-term concern of graduate schools in convincing students to pursue advanced degrees has been the concept of foregone income. It is perhaps clearest to note in the case of engineers right now. A student with a bachelor's degree in engineering can almost immediately go to work in the private sector at a salary of $25,000 - $35,000 (see Table 1). That is close to the range of Assistant Professors' salaries after completing a Ph.D. ($26,000 to $36,100 at comprehensive institutions). If one is concerned about the concept of foregone income, which is to say the income that one could earn after the bachelor's degree, that is not being earned while one is studying for an advanced degree, the foregone income cost of a graduate degree is increasing at a rate much faster than inflation. Couple that with the fact that the awards provided by the federal government, or private sector, or individual institutions, are now taxable and have been reduced in value since 1986 by approximately 15% across-the-board, and you realize why many of our policies seem to be at odds with each other at creating incentives for students to pursue graduate studies in science and engineering (see Table 2). Clearly, the NSF fellowship program is successful as are NIH traineeships and the new assistantships in areas of national need and they offer models that we would be delighted to see expanded.

Fellowships and traineeships help to provide a critical mass of scholars and researchers. We do not believe that the size of that critical core group is large enough. Make no mistake, scholars are not saying they should be tax-exempt or that they should not pay their fair share of taxes. The question has to do with reasonableness.

The Council of Graduate Schools believes that what would most help retore a reasonable approach to federal science policy is a balanced package of support as my colleague from Illinois has discussed. Increases in fellowship, traineeship, and assistantship support, coupled with expansion in competitive research awards, early identification efforts, and a restoration of federal facilities initiatives would provide the kinds of incentives that we believe would be effective in increasing the number of students in science and engineering while advancing this nation's ability to compete in a world economy.

Table 1

Average Starting Salaries for 1989 Bachelor's Graduates

Degree Field	Annual Salary
Engineering	$30,600
Chemical	32,604
Civil	30,036
Electrical	30,804
Industrial	29,832
Mechanical	31,116
Petroleum	35,148
Chemistry	28,488
Computer Sci	27,756
Math/Statistics	26,316

Source: Northwestern Lindquist
Endicott Report

Compiled by the Office of Information Services
Council of Graduate Schools

Table 2

Graduate Research & Teaching Assistant Stipends*

Academic Year 1988–1989

Institution	Research Assistantships	Teaching Assistantships
Boston College	$8,100	$8,100
Brown University	7,650	8,300
Cornell University	7,657	7,378
Dartmouth College	7,050	7,500
Georgia Institute of Technology	6,750	6,750
Lehigh University	8,100	8,000
Loyola University of Chicago	9,000	9,000
Michigan State University	9,338	9,331
New Mexico State University	7,862	7,862
Ohio State University	8,190	7,703
Pennsylvania State University	8,000	8,000
Princeton University	8,800	10,000
Southern Illinois University, Carbondale	7,000	7,000
Stanford University	8,389	8,650
State University of New York at Stony Brook	8,400	8,000
University of Alaska	10,500	6,000
University of California, Berkeley	8,249	10,634
University of California, Los Angeles	9,500	10,634
University of California, San Diego	8,175	10,634
University of California, Santa Cruz	8,250	10,634
University of Chicago	8,100	8,100
University of Connecticut	8,290	8,290
University of Idaho	8,049	7,356
University of Iowa	10,250	9,550
University of Kentucky	7,983	6,664
University of Louisville	8,000	8,000
University of Maryland, College Park	8,225	8,225
University of Notre Dame	7,200	8,200
University of Oklahoma	7,173	7,259
University of Southern California	8,658	8,656
University of Texas, Austin	7,358	7,713
University of Tennessee, Knoxville	8,331	7,303
University of Wisconsin, Madison	8,768	10,539
Wayne State University	9,500	9,000
Ranges	$6,750–$10,500	$6,000–$10,634

*Average stipend in science and engineering fields based on 50% appointment over 9 or 10 month academic year.

Source: CGS Survey, May 12, 1989

Compiled by the Office of Information Services
Council of Graduate Schools

Mr. **Walgren**. Thank you very much, Dr. LaPidus. Can you tell me more about why the numbers of fellowships are decreasing, aside from the tax side? Are the numbers of graduate stipends decreasing in actual availability?

Dr. **LaPidus**. There has been a real philosophical shift over the last 20 years from grant support to loan support. The large number of fellowships that were available in the mid-1960s, fellowships and traineeships at the level of about 80,000, has now dropped to about 12,000 as a result of conscious decisions to reduce these fellowships—we're talking about Federal fellowships now—and to move to a different mode of funding education, that being loans.

Mr. **Walgren**. I guess I'm—most of us got caught up in the tax leveling process and it really, from a Congressional standpoint, was not an effort to disadvantage anyone. In fact in the tax reform process of 1986 it was generally thought that we were providing uniform treatment rather than any particular disadvantage. I guess my questions then go, if that current is running broadly, then isn't our best defense to increase the actual support, either in numbers or in value?

Dr. **LaPidus**. Absolutely. The end result of all this is that the incentives, particularly the incentives in terms of providing reasonable living expenses so a student can go to school full-time are less now than they were. That's true because of a number of things.

One is that there are fewer fellowships available, another is that the Tax Reform Act in this attempt to approach a level playing field also decreased the amount. Now you can overcome that in a variety of ways, but what has to happen if we really want to encourage more students to go into school— and I think students are prepared to make financial sacrifices, but they have to some assurance of adequate support, in order to undertake this rather long haul of going on to graduate school—what has to happen is that there must be adequate support for them to do this.

Otherwise, they simply have too many other choices available. We're talking about bright kids who have a lot of things that they can do. They are looking for some signal that there is enough support for them to go on and do this kind of work.

Full-time work in the fields we are talking about, full-time graduate education, is generally talked about in terms of 70 hours or so a week in the laboratory and in the class room. There is simply no time to work on the outside.

Students have to find dollars so that they can live while they are engaged in this kind of work, whether we do it by changing the tax law or increasing the stipends, whatever, we have to put more money into this so that it happens.

Mr. **Walgren**. What's the trend in constant purchasing power of stipends over the 30 years? When you look back to the 1950s, were those at comparable levels? Have they kept up with inflation?

Dr. **LaPidus**. I don't think so. I think they've lagged behind inflation. But the range that I mentioned today, of basically $7,000 to $10,000—the $10,000 is quite high. Probably most of the stipends for graduate students today are in the area of $8,000 to $8,500.

That compares with stipends in the 1960s of $2,400, perhaps, for NIH trainees. That's the kind of comparison that we're looking at.

Students don't live like kings on that kind of stipend, but it is enough to get by.

Mr. **Walgren**. What tax bracket does that put them in?

Dr. **LaPidus**. In the 14 percent bracket, usually, depending on whether they have spouses and file jointly, and so on.

Mr. **Walgren**. When you look back at the 1950s, are there differences in the kind of support that brought a substantial number of people committed to graduate school in the 1950s? Dr. Liebman, did you have that in your testimony?

Dr. **Liebman**. Yes, as a matter of fact one of the biggest differences we see is traineeships. The number of traineeships really plummeted to practically nothing at the beginning of the 1970s. Traineeships provided a particularly stable block of funding that both faculty and students and the program that had the traineeships know it's there and know it will continue.

Mr. **Walgren**. Apparently, there is this difference between fellowships and assistantships?

Dr. **Liebman**. Let me explain in a little more detail the differences. An assistantship is a stipend given to work on a research project or for teaching at the institution.

A fellowship is an award given independent of a student's actual time investment in research or in teaching, and is given to the student individually as a national award.

Traineeship programs are a block grant that are provided to a program within an institution and then that program uses a traineeship to fund graduate students that they select individually to be admitted to that particular program.

Mr. **Walgren**. I see. And we've had a decrease in fellowships and traineeships?

Dr. **Liebman**. And a very large increase in assistantships, but the increase in assistantships has not been enough to outweigh the decrease in fellowships and traineeships. I believe the net decrease has taken us down to, well, I don't know the exact level now—

Dr. **LaPidus**. It's almost half. In other words, comparing to the total number available in the 1960s, and looking at the combination of assistantships, fellowships and traineeships, we're down now to just a little better than half of what was available in the early 1960s.

Mr. **Walgren**. So in terms of overall support for assistantships, fellowships and traineeships, the effective level is one-half in the late 1980s?

Dr. **LaPidus**. Close to that.

Mr. **Walgren**. That's from all sources?

Dr. **LaPidus**. Federal sources.

Mr. **Walgren**. Federal sources. Do you have any instinct for what the overall from all sources might be? State and local and perhaps school-based efforts have increased to fill the declining support from the Federal Government, but have increases from other sources been enough to replace the decline in Federal support?

Dr. **LaPidus**. No. There has been relatively little support of this type, particularly the fellowship and traineeship support, from industry and also from the states, and from the institutions themselves, there have been increases in the number of teaching assistantships provided and some increase in the number of research assistantships provided at those levels.

One of the points about fellowship and traineeship support is, as Dr. Liebman mentioned, for a student considering this rather long period of time to go on to school, that kind of support provides an assurance of multi- year funding. Assistantships are one year at a time, and depending on the source of that assistantship, it may have to do with enrollment or it may have to do with the particular time that a research grant expires. Those are a year at a time.

For a student looking at alternative sources of support, the assurance of long-term funding is extremely important. It makes it more attractive. If we're really talking here about making this kind of a choice more attractive to students, we're talking again about traineeships and fellowships, because those are the attractive kinds of support.

Mr. **Walgren**. I see. In making something attractive or having it be attractive to young people, certainly what they anticipate at the end of their graduate studies is something that they are considering very significantly, as well as the level of support that they are going to get in the meantime.

How big a factor do you feel was the nice pickup that they had in the 1960s at the end of graduate school compared to today? I gather the difference would be, perhaps in the 1960s there may not have been quite the lucrative present employment for them, the $100,000 foregone that you mentioned in your testimony, Dr. LaPidus. Has that changed?

Dr. **LaPidus**. One of the things that happened in the 1950s and 1960s is that there was tremendous expansion in universities in this country, and tremendous expansion in faculties. You had programs like the G.I. Bill and so on. Thousands of students were swarming universities and we needed more faculty. That dropped off to some extent in the 1970s and it is very clear now that as we look at the 1990s and beyond, we are facing terrific faculty shortages. There are going to be faculty jobs, good jobs, at good salaries for people going on.

The difficult point about all that is the lab period involved. As Dr. Liebman mentioned before, we're talking about five to seven years or longer to get the Ph.D. The faculty we need in the late 1990s are in college now. Again, the question before us is how to make them understand, first of all, that there are a lot of exciting and interesting things they can do in science and engineering, secondly that there are going to be jobs available in universities and in our technology-based industries, and that that's a good way to look at the rest of their lives.

Granted that the period in graduate school will result in foregone income, they will be making less than they would if they went directly into industrial positions, because there are good opportunities available.

Mr. **Walgren**. So one of the attractions for those who went on to graduate school in the 1960s was because they felt that there were faculty positions that might be available to them in the expanding university base. That has certainly has not continued. In fact, my instinct is that in recent past, faculty positions have been very limited.

Dr. **Liebman**. Except in engineering. Engineering has continued to expand. One of the big factors, most of the Ph.D.s back in the 1950s and 1960s went into academics. They saw the academic life as a very attractive life.

Now, I do not believe many of them see the academic as a very attractive life, because they see their professors working 70 and 80 hours a week in the laboratory, scrambling to keep multiple research projects going so that they can support the graduate students, they see a lot of pressure that was not there in the 1950s and 1960s.

One of the things we have to do in our institutions is to help take some of that pressure off the professors, so that the job looks more attractive, becomes more attractive.

Mr. **Walgren**. What are the present attractions for a Ph.D. other than university teaching? What kind of salary and demand is there for them in the private sector after graduate school as opposed to before?

Dr. **Liebman**. Industry is extremely interested in getting additional doctorates, not just in science and engineering, but in many other areas as well. In science and engineering, not only is industry providing a much higher salaries than academics, but they are able to supply them with better labs and more up-to-date laboratory equipment.

Mr. **Walgren**. But people are not going on to get the Ph.D.s because apparently there must not be—

Dr. **Liebman**. But at the same time that industry says it needs Ph.D.s, it also knows that it needs scientists and engineers coming out with masters degrees and bachelors degrees. It is offering very lucrative wages at those levels as well.

Mr. **Walgren**. The chair recognizes the gentleman from California, Mr. Campbell, for any questions. We want to see if we've covered the range—

In the past, post-doctoral fellows were able to exclude some $300 a month of their stipend for a period of years, and that exclusion as well, has been eliminated, is that correct?

Dr. **LaPidus**. Correct.

Mr. **Walgren**. Do you think that that has had a significant impact on things? What would that be, $300 a month, 14 percent of $300 is something like $42, or around in there, $42 a month? How much of this discouragement, translated into a lack of interest, do you feel is related to this kind of a tax uniformity current that has been flowing in the Government, compared to these larger factors of $100,000 in these years on the plate that would not be on the plate, the lack of the kind of pickup that graduate students anticipated, I gather, in the 1960s that they may not feel is there at least over and above their present pickup when they graduate from the academic programs? How would you weight these two elements?

Dr. **LaPidus**. I don't think anyone knows the answer to that, Mr. Walgren. The change in the tax code is recent, as you know, and we've had hundreds of calls from students all over the country who are very concerned about it. What the long range impact of that will be I think is difficult to predict. In one way, it's not a lot of money.

The concern that we have is that it seems that there is a set of circumstances that are all coming together at the same time, that in its totality is discouraging to people who want to consider going in this direction. That seems to be happening at a time when we're very concerned about the decline of interest in this area. That's what we're worried about.

So the changes in the tax law, the bite that they take out of the stipend, is part of a bigger picture that all adds up to a student saying "I don't know if I want to do this. It doesn't look like a terrific idea, particularly where there are other attractive options available."

If we don't get more students doing the kind of thing that we've been talking about, going on to graduate school, getting these degrees, going into universities, going into industry, and so on, we are increasingly dependent on other parts of the world for our science and technology base and for our university education.

Mr. WALGREN. I see. I remember in the 1960s, I think it was in the 1960s, that people with Ph.D.s really found very little employment. I don't know whether it was within specific disciplines, perhaps it was. But I remember stories about people with certain graduate degrees having to drive taxicabs.

I guess I'm wondering how deeply felt that experience was, whether that lingers in people's minds, that they feel that there are these cyclical impacts on a given area, and perhaps feel that they don't want to be caught in that.

Dr. LIEBMAN. It certainly lingers in the areas of the humanities. I don't think it was ever true in science and engineering, but that feeling does linger in the humanities. There is a lot of concern on the part of current humanities faculty members. They don't want to bring more graduate students than their own market can take.

Mr. WALGREN. And that's more a function of the size of the student body, because they can only look to teaching positions, by and large, as being able to uniquely use that level of training.

The gentlewoman from Maryland, Mrs. Morella, do you have any questions?

Mrs. MORELLA. Thank you, Mr. Chairman.

I'm very interested in reading your testimonies, in that I care very much about higher education and making it available to our students, but I have no questions.

Mr. WALGREN. Well, thank you very much on behalf of the Committee. We appreciate your participating in our process and we look forward to your being a resource to us in the future. Thanks very much.

The Chair will call the second panel, consisting of Jerry Caulder, the President of Mycogen Corporation of San Diego, California, John Swihart, President of the National Center for Advanced Technologies, and William Poulos, who is involved in Government Affairs for Apple Computer.

Welcome, gentlemen. As you know, your written statements will be reproduced in the record, and you can feel free to underscore portions of it or emphasize points in any way that you feel would communicate best to the transcript and to us. So let's go through the panel in the order in which I introduced you to the record. Let's start with Dr. Caulder.

STATEMENT OF JERRY D. CAULDER, PRESIDENT AND CEO, MYCOGEN CORPORATION, SAN DIEGO, CALIFORNIA

Dr. CAULDER. Thank you very much, Mr. Chairman, for allowing me to speak today. I'm Jerry Caulder, President and CEO of Mycogen Corporation.

The ability of the United States to remain competitive is directly related to our ability to remain *the* and not *a* leader in science and technology.

The United States has become the science and technology colony for the world. In the past few hundred years the colonial system worked very well, the mother country would colonize areas in the world in order to have access to raw materials. These raw materials would be brought home, converted to consumer goods and then resold to the colonies with the value added and the profits being retained by the mother country.

The raw materials of the past were natural resources, iron, bauxite, oil and forestry products, things of this sort. The raw materials of today and the future are science and technology.

I don't need to report the grim statistics that we have exported ten times more technology than we have imported over the last few years. I don't need to repeat that foreign countries now apply for and receive more U.S. patents than United States scientists.

At issue is the notion that those who control the patents are in the best position to exploit the technology. A more compelling argument, however, is that those who have access to the initial research and development will have the inside track to these patents. Therefore, the fact that we are losing the patent race is just a quantification of the fact that we started losing the R&D race a few years ago.

We have become a nation of scientific illiterates. Most people do not understand the difference between science and technology. Science is the pursuit of new knowledge. Technology is the conversion of this new knowledge into useful products or services.

We have had the best system in the world and the best system that the world has ever known for the efficient interaction of science and technology. The Government and universities performed the basic scientific research, this was supported by taxpayers dollars. These new discoveries were then available for all companies and industries to convert these technologies and create whole new industries like electronics and biotechnology. Capricious tax laws and funding policies of this R&D have dismantled that system.

Obviously, this is an extremely complex subject and I could speak all day about how we fund R&D, but today I would limit my remarks to just three areas of the tax law that need to be changed immediately, in fact, made retroactive, in order to reverse this trend, and assure that the fruits of R&D efforts make the United States as competitive as we can be in the future.

More jobs are created each year by small companies than all the Fortune 500 companies combined. More new technologies and products are incubated and brought to the consumers through small start-up companies than through large companies. The new tax laws are punitive and inhibitory to the start-up of small high-tech companies.

Let me highlight just three.

First, the R&D tax credit should be restored and made permanent. We need to be able to plan, rather than guess, what our financial commitments will be when investing in long-term, high-risk research endeavors.

Second, the alternative minimum tax is a very punitive tax for a small company. We need to attract the very best minds that we can, and we cannot compete with the DuPonts, Exxons and the Monsantos on a cash basis. This makes us do that.

The people that I recruited at Mycogen all took severe pay cuts in exchange for incentive stock options, in the hope that through hard work and dedication, we could make the company successful and therefore increase the equity value of these stocks, recouping their losses. The alternative minimum tax killed that incentive.

Third, the repeal of the capital gains tax puts a small company into head to head competition for talent with the large companies on a strictly cash basis. All we do now is delay their income. We are going to lose that battle because small companies are always very short of cash.

You have just heard previous testimonies that the number of Ph.D.s in science and technology is going to be diminishing. This will put us at a further disadvantage when we try to compete for the fewer and fewer numbers of people that we are graduating.

Let me get in a small commercial plug for the high- tech company I work for, Mycogen. Our mission is very simple. We are using biotechnology or gene splicing to develop a whole new family of products that can replace chemical pesticides. Our products are all naturally occurring and completely biodegradable. They don't build up in groundwater and they do not contaminate food and exist as residues when we consume that food.

We are on a mission to change an industry. I need the very best talent that the U.S. has to offer. We've been hearing over and over that we need incentives for people to do things.

My father is an 82-year old cotton farmer. He still farms every day. He used to tell me, "Son, those things that get rewarded get repeated." Let's make sure that we get the right things rewarded, so that we get the right things repeated.

I spend a lot of my time trying to create value through doing deals. The Japanese are making products. We need to change what we reward in this country.

Thank you very much.

[The prepared statement of Dr. Caulder follows:]

TESTIMONY BEFORE THE U.S. HOUSE OF REPRESENTATIVES SUBCOMMITTEE ON SCIENCE, RESEARCH AND TECHNOLOGY

PRESENTED BY JERRY D. CAULDER, PH.D., PRESIDENT AND CEO
MYCOGEN CORPORATION, SAN DIEGO, CALIFORNIA
MAY 18, 1989

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We had the best system the world has ever known for the most efficient interaction of science and technology. The government and universities performed the basic scientific research, supported by the tax payers' dollars, and these new discoveries were available for all industries to convert to technology and create whole new industries like electronics and biotechnology. Capricious tax laws and funding policies have dismantled that system.

Obviously this is an extremely complex subject and I could speak all day about how we fund R&D, but today I will limit my remarks to just three areas of the tax law that need to be changed immediately, in fact made retroactive, in order to reverse this trend, and assure that the fruits of R&D efforts make the United States as competitive as we can be in the future.

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We spend a lot of time doing deals with investment bankers while the Japanese are making products.

Thank you for allowing me to speak before you today.

Mr. **Walgren**. Thank you, Dr. Caulder.
We'll turn to Mr. Swihart.

STATEMENT OF JOHN SWIHART, PRESIDENT, NATIONAL CENTER FOR ADVANCED TECHNOLOGIES, WASHINGTON, D.C.

Mr. **Swihart**. Thank you very much, Mr. Chairman. My name is John Swihart, I'm the President of the National Center for Advanced Technologies. It's a non-profit foundation formed by the Aerospace Industries Association of America, the AIA. Prior to my association with NCAT, as the Center is referred to, I retired as a Corporate Vice President of the Boeing Company with over 26 years of service. Before that, I worked for NASA for 13 years. Both there and at Boeing, I was very involved with the evolution of aerospace technology.

The severity of the foreign challenge to the U.S. aerospace industry makes our position very clear. We must improve our ability to compete in the world market. My recommendation is to focus on the enhancement of U.S. technology development. We have the technological tools, the facilities, the managerial expertise, and the technology base. What we're desperately in need of is a new approach.

Compared to what we could be accomplishing, our current technology development process is a fragmented, often duplicative, lengthy and risky approach to product development. Our foreign competitors have turned their technological development efforts into national goals, and the positive results are quite impressive.

Toyota, for example, goes from their preliminary designs to finished cards in only 36 months. Our best effort here in the United States, from the Ford Company, goes from drawing board to completed product in 60 months. We of the aerospace industry have been concerned about the inadequacies of our technological development for some time, and decided that something had to improve before it was too late.

The AIA has sponsored a program known as the Key Technologies of the 1990s. It involves the focusing of developmental effort on a number of key technologies selected on the basis of highest leverage, greatest potential payoff, and broadest applicability to both civil and military products.

Under the AIA program, the industry, the research universities, and the Government laboratories function as a coordinated team, each contributing to the generic technology bank from basic research through the technology development phase. This team approach will help ensure technology readiness, thereby avoiding costly duplication and excessive risk.

Once a technology reaches a reasonable risk state of maturity, the industry participants will then individually pursue their own product development efforts in a competitive environment.

Let me emphasize that the Key Technologies Program is not just a proposal, but an active program on which the AIA has been working for the past three years. For the record, I have included material describing some of the individual key technologies and an overview brochure describing the program.

At the moment, our principal task is the reconstitution of the Government portion of the aerospace technology forum. This group consists of the top level industry, Government, academia policy-making personnel that provide overall direction for the program.

A list of participants in the original forum has been included for the record. We must now contact the Bush Administration people to rebuild the Government portion of the forum.

As always, research and development programs require considerable industry investment. Government sponsored incentives would encourage investment, and confirm Federal acceptance of this national technology development effort.

At this point, I would stress that I am speaking for the entire aerospace industry and the following incentives include those that apply to both Government and commercial contractors.

To begin with, tax credits for R&D should be expanded. They should be made permanent. Currently, they benefit only companies that increase their research and development investment. They should also be made available to support companies that invest at consistent levels, as well as to new and small businesses, as we just heard. Some special tax credit to incentivize cooperative efforts between industry and the academic community would also be very supportive. The stable funding of Government programs is another major requirement for industry technology developments. AIA supports biennial budgeting and expanded multi-year procurement.

Simplification of the Federal acquisition system is also very much needed. Over the past two years, DOD has successfully instituted a number of streamlining measures, but more remain to be made. AIA estimates that a greatly simplified, more consistent procurement process could reduce the time it takes to develop, produce and field a major weapon system by up to 50 percent.

Additionally, DOD should develop a firm and consistent policy that clarifies technical data rights and protects industry's proprietary rights to intellectual property.

Independent Research and Development, or IR&D, is a normal cost of doing business. The Government should recognize this, and industry should be able to allocate to the Government its full share of actual IR&D and bid and proposal costs without the ceiling limitations.

We believe there is also a need to provide for adequate key technology validation demonstrations. The Government should provide the framework to see that the most critical validation demonstrations are performed well before major development programs are started.

Last, but certainly not least, is the need to build a better science education infrastructure through incentives for teaching at all education levels, from college to secondary to elementary level programs. Science and mathematics are particularly important, but good communications skills are also needed.

To summarize, those of us in the aerospace industry, the Government, and the universities, who have helped to initiate the Key Technologies effort, believe that significant improvements can be realized before the turn of the century, improvements that will enable truly fantastic developments in the long term, and enhance the U.S. position in the international marketplace.

To attain these results, we believe that the necessary ingredients are: significant goals, that is, double the productivity of the available resources and halve the time from idea to use; industry playing a key role in a cooperative partnership with Government and academia; focus on the key technologies providing the highest economic leverage; and a positive policy environment to encourage the success of a new U.S. technology development process.

I want to thank you, Mr. Chairman, for giving me the opportunity to tell you that we sincerely want to work with this Administration and the Congress. If we approach U.S. industry competitiveness as a team, we feel our position in the international marketplace can be remarkably improved.

This concludes my presentation.

[The prepared statement of Mr. Swihart follows:]

TESTIMONY OF JOHN M. SWIHART

ON BEHALF OF

AEROSPACE INDUSTRIES ASSOCIATION OF AMERICA, INC.
AND
THE NATIONAL CENTER FOR ADVANCED TECHNOLOGIES, INC.

BEFORE THE
SUBCOMMITTEE ON SCIENCE, RESEARCH AND TECHNOLOGY
HOUSE SCIENCE, SPACE AND TECHNOLOGY COMMITTEE

MAY 18, 1989

Mr. Chairman and Members of the Subcommittee:

My name is John Swihart. I am the President of the National Center for Advanced Technologies (NCAT), a non-profit foundation formed by the Aerospace Industries Association of America (AIA). Prior to may association with NCAT, I retired as a Corporate Vice President of the Boeing Company with over 25 years of service. Before that I worked at NASA for 13 years and both there and at Boeing I was very involved with the evolution of aerospace technology.

AIA represents 50 of the nation's major manufacturers of commercial, military and business aircraft, helicopters, aircraft engines, missiles, spacecrafts, and related components and equipment.

We in the aerospace industry are deeply concerned about American industrial competitiveness in general and the future competitiveness of our own industry in particular.

The U.S. is losing competitive momentum across a broad spectrum of industrial activities. The Japanese and other industrialized nations are beating us to death in many areas of trade. In some markets, the U.S. has been virtually eliminated.

Even in high technology products, an area traditionally dominated by the U. S., our trade balance on occasion dips into the red. In aerospace, the last bastion of American trade superiority, even though we are reporting large positive trade balances, but we

ARE GRADUALLY LOSING GROUND. THE SEVERITY OF THE FOREIGN COMPETITIVE CHALLENGE MAKES OUR POSITION CLEAR. UNLESS IMMEDIATE ATTENTION IS TAKEN, WE WILL CONTINUE TO LOSE GROUND AND THIS COULD HAVE A SERIOUS IMPACT AS INTERNATIONAL PARTNERSHIPS CONTINUE TO BE ESTABLISHED.

HOW DID THIS SITUATION COME ABOUT?

THERE HAVE BEEN A GREAT MANY CONTRIBUTING FACTORS, BUT IN MY OPINION THE DOMINANT ONE RELATES TO OUR TECHNOLOGY DEVELOPMENT ATTITUDE. IN THE WAKE OF WORLD WAR II, THE REBUILDING NATIONS OF EUROPE AND JAPAN LEARNED A LESSON FROM AMERICA -- THAT THERE IS A DIRECT CORRELATION BETWEEN A NATION'S TECHNOLOGICAL PROWESS AND ITS PROSPERITY. EACH OF THE MAJOR INDUSTRIALIZED NATIONS MOUNTED AN INTENSIVE PROGRAM OF R&D TO UPGRADE ITS TECHNICAL COMPETENCE. THEY HAVE CONTINUED THESE PROGRAMS UNRELENTINGLY EVER SINCE AND THEY HAVE SCORED IMPRESSIVE SUCCESSES.

THE U.S. DID NOT BY ANY MEANS ABANDON ITS TECHNOLOGY DEVELOPMENT. THERE WAS, HOWEVER, A FAILURE TO RESPOND TO THE CHALLENGE AS VIGOROUSLY AS THE SITUATION WARRANTED. AS EVIDENCE, DURING THE LAST DECADE OR MORE, WE HAVE BEEN DRAWING HEAVILY ON THE U.S. TECHNOLOGY BASE, A BASE ESTABLISHED MAINLY DURING THE '50S AND '60S. UNFORTUNATELY OVER THE PAST TWENTY YEARS, WE HAVE NOT SIGNIFICANTLY UPGRADED OUR TECHNOLOGY EFFORT. IN MANY AREAS, WE ARE STILL RELYING ON THE ADOPTION OF OUTMODED TECHNOLOGIES TO PRODUCE COMPETITIVE PRODUCTS.

My recommendation for a method of revitalizing the U. S. competitive position is to focus on the enhancement of the U.S. technology development. We will still take what benefits we can get from trade legislation, negotiations with our trading partners and the trade advantages from monetary exchange rates. But these latter measures are aids, not solutions. In this era of internationalism, partnerships are formed between those who have the most to offer. At present, for example, both Japan and the United States stand to gain through cooperative ventures. By 1992, when the European Community foresees itself as having a strong and highly competitive technological capability, it may benefit a country like Japan to seek business partnerships in Europe rather than the U.S.

I believe the core of our U.S. solution is a bold national program of technology development aimed at bringing to the international marketplace a line of U.S. products of such undisputed excellence that they will dominate the marketplace. I'm talking about products across a broad spectrum, not exclusively aerospace. We must deal with high technology products whose higher values make them especially important in the world trade equation.

We have the technological tools to make this possible: the facilities, the managerial expertise and the technology base. What we need now is a new approach to R&D. We have to speed up the process.

Let me clarify that statement. The technology development cycle is a lengthy and risky process. From the time a potentially promising technology is created in some university lab, until the time it appears on a commercial product, many years can pass. Consider the common cathode ray tube of our television sets. It was developed long before World War II but did not become widely used in commercial airplane cockpit displays until the past half dozen years.

Technology application is the final link in a long chain of developmental activities. As I mentioned, the basic research begins in a lab somewhere. From there the technology moves into applied research where its potential is more closely examined. Next, the technology must be validated. In this step, the proof of concept is established. Following that, the technology must be demonstrated to prove its potential. If all goes well, the technology is finally ready for full scale application development.

For those of you who may not have a feeling for how long this whole procedure takes, let me give you a typical example. Historically, in the application of new technology to commercial airplanes, some ten to twelve years elapse just between the time basic research is complete and the time the technology is ready to undergo application development. I should add that still more time has to pass before the technology is actually ready to take its place on the production line. Compared to what we could be accomplishing, our current technology development process is a fragmented, often duplicative and lengthy approach to product development.

I have taken time to mention the details of the technology

DEVELOPMENT PROCESS BECAUSE I WANT TO MAKE THE POINT THAT THIS PROCESS REPRESENTS BOTH OUR TRADITIONAL AND CURRENT APPROACH TO THE REALIZATION OF ECONOMIC BENEFIT THROUGH NEW TECHNICAL DISCOVERIES. I ALSO WANT TO MAKE THE POINT THAT ALTHOUGH MANY OF OUR FOREIGN COMPETITORS GO THROUGH ESSENTIALLY THE SAME STEPS, THEY HAVE BEEN FAR MORE SUCCESSFUL THAN WE HAVE IN REDUCING THE OVERALL DEVELOPMENT TIME. THEY MADE THE EFFORT A NATIONAL GOAL AND THE POSITIVE RESULTS ARE QUITE EVIDENT. TOYOTA, FOR EXAMPLE, GOES FROM THEIR PRELIMINARY NEW MODEL DESIGNS TO FINISHED CARS IN ONLY 36 MONTHS. OUR BEST EFFORT HERE IN THE U.S. COMES FROM THE FORD COMPANY; THEY TAKE 60 MONTHS FROM DRAWING BOARD TO COMPLETED PRODUCT. THE U.S. STILL RANKS AT THE TOP WHEN IT COMES TO CREATIVITY, BUT WE TAKE TOO LONG TO GET TO THE MARKET WITH OUR PRODUCTS.

WE OF THE AEROSPACE INDUSTRY HAVE BEEN CONCERNED ABOUT THE INADEQUACIES OF OUR R&D PROCESS FOR SOME TIME AND DECIDED THAT SOMETHING HAD TO IMPROVE BEFORE IT WAS TOO LATE.

AEROSPACE INDUSTRIES ASSOCIATION HAS SPONSORED THE DEVELOPMENT OF A NEW APPROACH, THE KEY TECHNOLOGIES FOR THE 1990S PROGRAM. IT SEEKS TO MAKE THE EXPENSIVE PROCESS OF TECHNOLOGY DEVELOPMENT MORE AFFORDABLE BY TAKING ADVANTAGE OF THE EFFICIENCIES INHERENT IN A NATIONAL COOPERATIVE PROGRAM.

THIS PROGRAM INVOLVES FOCUSED DEVELOPMENTAL EFFORT ON A NUMBER OF KEY TECHNOLOGIES SELECTED ON THE BASIS OF HIGHEST LEVERAGE, GREATEST POTENTIAL PAYOFF AND BROADEST APPLICABILITY TO BOTH CIVIL AND MILITARY PRODUCTS. EACH KEY TECHNOLOGY MUST BE AFFORDED

PRIORITY AND MUST BE DEVELOPED ON AN ACCELERATED BASIS AS A NATIONAL INITIATIVE OF INDUSTRY, GOVERNMENT AND ACADEMIA, EACH CONTRIBUTING ITS SPECIAL CAPABILITIES IN A CLOSELY COORDINATED TEAM EFFORT.

BY BRINGING THESE TECHNOLOGIES TO MATURITY ON AN ACCELERATED SCHEDULE AND APPLYING THEM TO ADVANCED PRODUCTS AHEAD OF OUR COMPETITORS, THE U.S. WOULD GAIN ENORMOUS BENEFIT NOT ONLY IN TRADE COMPETITIVENESS BUT IN NATIONAL SECURITY CAPABILITY. AND BECAUSE OF THE BROAD APPLICABILITY OF THE TECHNOLOGIES SELECTED, THE BENEFITS WOULD EXTEND BEYOND THE AEROSPACE/DEFENSE INDUSTRY TO MANY AMERICAN INDUSTRIES. THESE TECHNOLOGIES ARE ALL DUAL-USE TECHNOLOGIES THAT ARE APPLICABLE TO BOTH GOVERNMENT AND COMMERCIAL PRODUCTS.

UNDER THIS PLAN, THE TECHNOLOGY DEVELOPMENT AND INTEGRATION PROCESS WILL BE SUBSTANTIALLY DIFFERENT THAN THE TRADITIONAL PROCESSES I DESCRIBED.

UNDER THE AIA PROPOSAL, THE INDUSTRY, RESEARCH UNIVERSITIES AND GOVERNMENT LABORATORIES WOULD FUNCTION AS A COORDINATED TEAM, EACH CONTRIBUTING TO THE GENERIC TECHNOLOGY BANK FROM BASIC RESEARCH THROUGH THE TECHNOLOGY DEVELOPMENT PHASE - THUS AVOIDING COSTLY DUPLICATION AND REDUCING RISK BEFORE ANY ATTEMPT IS MADE TO APPLY THE TECHNOLOGY TO A PRODUCT. THIS PRE-COMPETITIVE COOPERATION WOULD AVOID UNWARRANTED DUPLICATION OF EFFORT AND PROVIDE A BROADER TECHNOLOGY BASE IN KEY AREAS OF WORK.

WHEN A TECHNOLOGY REACHES A "REASONABLE RISK" STATE OF MATURITY, INDUSTRY PARTICIPANTS WILL INDIVIDUALLY PURSUE THEIR OWN

PRODUCT DEVELOPMENT EFFORTS IN A COMPETITIVE ENVIRONMENT.

AIA BELIEVES THAT THE NATIONAL TECHNOLOGY DEVELOPMENT APPROACH COULD EFFECT A TWO TO ONE INCREASE IN THE PRODUCTIVITY OF AVAILABLE RESOURCES AND CUT IN HALF THE TIME IT TAKES TO DEVELOP AND FIELD TECHNOLOGY. MOST IMPORTANTLY, THIS PROGRAM AIMS TO MAKE AVAILABLE -- BEFORE THE TURN OF THE CENTURY -- THE TECHNOLOGICAL TOOLS AMERICAN INDUSTRY NEEDS TO COMPETE MORE EFFECTIVELY.

LET ME EMPHASIZE THAT KEY TECHNOLOGIES IS NOT JUST A PROPOSAL BUT AN ACTIVE PROGRAM ON WHICH AIA HAS BEEN WORKING FOR THE PAST THREE YEARS. I HAVE INCLUDED MATERIAL DESCRIBING SOME INDIVIDUAL TECHNOLOGIES AND AN OVERVIEW BROCHURE ON THE KEY TECHNOLOGIES PROGRAM.

IN JANUARY, AIA TOOK ANOTHER MAJOR STEP TOWARD REALIZING A NATIONAL TECHNOLOGY DEVELOPMENT STRATEGY WITH THE ESTABLISHMENT OF THE INDUSTRY SPONSORED NATIONAL CENTER FOR ADVANCED TECHNOLOGIES (NCAT). NCAT IS REAL EVIDENCE OF THE AEROSPACE INDUSTRY'S RECOGNITION OF THE IMPORTANCE OF THE TECHNOLOGY DEVELOPMENT PROCESS AND ITS COMMITMENT TO ADVANCING THE PROCESS.

NCAT HAS TWO MAJOR RESPONSIBILITIES: IT WILL HANDLE THE DAY-TO-DAY COORDINATION OF THE KEY TECHNOLOGIES PROGRAM, AND IT WILL SERVE AS A DATA REPOSITORY FOR PROGRAM DECISION-MAKING. ITS INITIAL ASSIGNMENT IS TO PULL TOGETHER EVERYTHING THAT IS BEING DONE IN THE KEY TECHNOLOGY AREAS, CREATING AN UP-TO-THE-MINUTE, SPECIALIZED DATA BASE OF GREAT VALUE TO THOSE COMPANIES AND GOVERNMENT AGENCIES PARTICIPATING IN THE PROGRAM.

We are developing roadmaps for each of the Key Technologies. We have already completed four of them and four more are in coordination.

In coming months, the principal key technologies task is reconstitution of the Aerospace Technology Policy Forum. The group consists of the top level industry government academia policy making personnel that will provide overall direction of the program. Last year we were able to enlist the support of upper level Reagan Administration officials representing the major technology developing agencies. We request that this list be included in the record. We must now rebuild the forum to include their successors in the Bush Administration. Once that task is accomplished, and the remaining roadmaps completed, we will begin in earnest the implementation of the Key Technologies program.

Our next steps involve preparation of national technology development plans for each of the Key Technologies and the creation of plans for technology validation demonstrations to ensure applications of the technology.

With this program, the aerospace industry has taken the leadership in advancing American competitiveness. We think our program is an excellent model for other U.S. industries to pursue. But if this program is to realize its full potential, industry will need strong support from the Congress and the Administration.

As always, R&D programs require considerable industry

INVESTMENT. GOVERNMENT SPONSORED INCENTIVES TO SUCH INVESTMENTS WOULD ENCOURAGE THE EFFORT AND CONFIRM FEDERAL ACCEPTANCE OF THIS NATIONAL EFFORT.

AT THIS POINT, I WOULD STRESS THAT I AM SPEAKING FOR THE AEROSPACE INDUSTRY AND THE FOLLOWING DISCUSSION OF INCENTIVES INCLUDES THOSE THAT APPLY TO BOTH GOVERNMENT AND COMMERCIAL CONTRACTORS.

TAX CREDITS FOR R&D SHOULD BE EXPANDED.

- O THE TAX CREDIT SHOULD BE MADE PERMANENT IN ORDER TO PERMIT LONG TERM PLANNING.
- O IT SHOULD BE MADE AVAILABLE TO SUPPORT COMPANIES WHO INVEST AT CONSISTENT LEVELS. (IT CURRENTLY ONLY BENEFITS COMPANIES WHOSE R&D INVESTMENT INCREASES.)
- O IT SHOULD ALSO BE MADE AVAILABLE TO NEW AND SMALL BUSINESSES.
- O THERE SHOULD BE A SPECIAL TAX CREDIT TO INCENTIVIZE COOPERATIVE EFFORTS BETWEEN INDUSTRY AND THE ACADEMIC COMMUNITY.

A MAJOR REQUIREMENT FOR INDUSTRIAL TECHNOLOGY DEVELOPMENT IS STABLE FUNDING OF GOVERNMENT PROGRAMS. AIA SUPPORTS BIENNIAL

BUDGETING AND EXPANDED MULTIYEAR PROCUREMENT.

ANOTHER MAJOR NEED IS SIMPLIFICATION OF THE FEDERAL ACQUISITION SYSTEM. DOD HAS, OVER THE PAST TWO YEARS, INSTITUTED A NUMBER OF STREAMLINING MEASURES, BUT A LOT REMAINS TO BE DONE. AIA BELIEVES, AS DID THE PACKARD COMMISSION, THAT A GREATLY SIMPLIFIED, MORE CONSISTENT PROCUREMENT PROCESS WOULD ENABLE US TO CUT IN HALF THE TIME IT TAKES TO DEVELOP, PRODUCE AND FIELD A MAJOR WEAPON SYSTEM; THAT WOULD MEAN ENORMOUS SAVINGS TO THE GOVERNMENT.

ADDITIONALLY, DOD SHOULD DEVELOP A FIRM AND CONSISTENT POLICY THAT CLARIFIES TECHNICAL DATA RIGHTS AND PROTECTS INDUSTRY'S PROPRIETARY RIGHTS TO INTELLECTUAL PROPERTY.

OF PARTICULAR IMPORTANCE TO GOVERNMENT CONTRACTORS IS INDEPENDENT RESEARCH AND DEVELOPMENT OR IR&D. IR&D IS COMPANY INITIATED R&D THAT EXPLORES ADVANCED CONCEPTS AND CREATES NEW PRODUCTS AND PROCESSES THAT MAKE A COMPANY MORE COMPETITIVE. IT IS A COMPANY'S INVESTMENT IN ITS FUTURE, AND IS, IN AIA'S VIEW, THE VERY BEST EXISTING MECHANISM FOR NEW TECHNOLOGY DEVELOPMENT LEADING TO SUPERIOR U.S. AEROSPACE PRODUCTS. THE GOVERNMENT SHOULD RECOGNIZE THAT IR&D IS A NORMAL COST OF DOING BUSINESS AND INDUSTRY WOULD BE ABLE TO ALLOCATE TO THE GOVERNMENT ITS FULL SHARE OF ACTUAL IR&D/B&P COSTS WITHOUT CEILING LIMITATIONS.

THE GREATEST PRESSURE ON GOVERNMENT CONTRACTORS IS THE NEED TO ENSURE ADEQUATE PROFIT LEVELS TO ALLOW FOR INDUSTRY LONG TERM INVESTMENTS. ANY HIGH TECH INDUSTRY WILL WITHER IF IT CANNOT PROVIDE FOR LONG TERM R&D AND THE ABILITY TO DEVELOP NEW TECHNOLOGY to risk-acceptable readiness. This was discussed in considerable detail in the industry sponsored MAC Group study entitled "The Impact on Defense Industrial Capability of Changes in Procurement and Tax Policy," which reviewed the effects of procurement policy changes from 1983-1987. A copy is provided for the record.

We believe there is also a need to provide for adequate Key Technology validation demonstrations. All of us, those in the aerospace industry, the government technology folks, and the university experts need to agree on what those validation demonstrations are and also which are of the highest priority. The government should provide the framework to see that the most critical validation demonstrations are performed well before major development programs are started.

And last, but certainly not least, is the need to build a better science education infrastructure through incentives for teaching at all education levels. There is a need to develop programs at the college level for near term benefits, but students must be prepared through better elementary and secondary education programs before they get to college. The math and science education efforts are obvious choices for emphasis, but communication skills and foreign language skills are also important. This problem is particularly acute for the aerospace industry which is already international in scope.

In summary, we need a new national approach to successfully

COMPETE IN TOMORROW'S WORLD.

WE BELIEVE THE ESSENTIAL INGREDIENTS ARE:

- O SIGNIFICANT GOALS I.E., DOUBLE THE PRODUCTIVITY OF AVAILABLE RESOURCES AND HALVE THE TIME FROM IDEA TO USE;
- O INDUSTRY PLAYING A KEY ROLE IN A COOPERATIVE PARTNERSHIP WITH GOVERNMENT AND ACADEMIA;
- O FOCUS ON THE KEY TECHNOLOGIES PROVIDING HIGHEST ECONOMIC LEVERAGE; AND
- O A POSITIVE POLICY ENVIRONMENT TO ENCOURAGE THE SUCCESS OF A NEW U.S. TECHNOLOGY DEVELOPMENT PROCESS.

WE THINK KEY TECHNOLOGIES FOR THE 1990S CAN PRODUCE THE CHANGES OUR NATION NEEDS TO MAKE IF WE ARE TO REMAIN COMPETITIVE. IN ADDITION, WE FEEL THE PROGRAM IS FAR ENOUGH ALONG TO BE USED AS A MODEL FOR OTHER INDUSTRIES.

WE ARE ENCOURAGED BY THE INCREASING NATIONAL INTEREST IN TECHNOLOGY DEVELOPMENT, PARTICULARLY THE DEPARTMENT OF COMMERCE TECHNOLOGY ADMINISTRATION AND THE RECENT COMMENTS OF SECRETARY MOSBACHER. WE WANT TO WORK WITH THEM, THE ADMINISTRATION, AND CONGRESS TO IMPROVE OUR INDUSTRIAL COMPETITIVENESS IN THE

INTERNATIONAL MARKETPLACE.

THAT CONCLUDES MY PRESENTATION. I WILL NOW RESPOND TO ANY QUESTIONS YOU MAY HAVE.

Mr. HAYES. Thank you. The Chair recognizes the gentleman from California, whom I believe wishes to make the next introduction for the panel.

Mr. CAMPBELL. I thank the Chair and I thank you for your courtesy. I will take just a moment to draw your attention to the testimony of Mr. Bill Poulos, which we are about to hear. Bill represents the Apple Computer Corporation, which is headquartered in Cupertino, in the Silicon Valley. That of course, is very important to me.

What may be important to the rest of you is that Apple is a unique success story in the United States. Three years ago it had 5,000 employees, and a gross sale of $2 billion. Within three years it had doubled employment size to 10,000 and more than doubled gross sales to $5 billion.

Perhaps most telling of all, because of our topic today in competitiveness, is that the productivity of Apple Computer, to the best of our unbiased California-oriented research, is number one in the United States. That is to say, Apple Computer has a per-employee productivity of $400,000. So I appreciate the Chair's courtesy and ask my colleagues to pay special attention to what this company's experience has to teach us.

Thank you, Mr. Chairman.

STATEMENT OF BILL N. POULOS, GOVERNMENT AFFAIRS OFFICE, APPLE COMPUTER, INC., WASHINGTON, DC

Mr. POULOS. Thank you, Congressman. Mr. Chairman, I will be speaking from an abbreviated three-page statement, although we have provided a longer, detailed statement for the record.

The driving motivation behind Apple research and development is an unwillingness to be satisfied with our present level of achievement. Two college drop-outs dreamed of a machine that would bring computing power into the homes and offices of the individual. Out of this dream came Apple Computer, and the birth of the personal computer industry.

It is important to state at the outset that we do not expect our Government to provide the industrial dreams and vision for the future. We do not expect our Government to provide the ideas for research and experimentation, but we do expect our Government to provide a national economic environment which fosters creativity, vibrancy and vision. Our Government must provide the fertile conditions wherein new ideas and technological ingenuity can flourish and come to fruition.

The current political and economic environment is fraught with problems which distract business leaders from their primary responsibility. For example, while R&D is a long-term investment, the R&D tax credit has become a short- term policy which will have expired three times by December 1989. How can a company base long-term decisions on a Congressional policy which cannot be counted on from one year to the next?

Because rapid changes in technology and business conditions demand high levels of attention from our management, we can scarcely afford to concentrate on this "she loves me, she loves me not" Congressional tax policy.

Stability must also be found in the administration of tax policy. Treasury is now attempting to define the rules for tax credit treatment eight years after the fact.

In the absence of regulation, but in accordance with the plain intent of Congress, Apple Computer treated all wages subject to withholding as qualifying expenditures for the R&D credit if those employees were in fact involved in the R&D process.

The IRS is now telling us that one form of taxable wages, that of employee stock options, is a special exception and cannot be used for R&D credit calculation.

It was Apple's R&D team of creative technologists in this period that produced the easy to use graphics interface which the MacIntosh is so famous for. It is the compensation of these R&D visionaries that the IRS now refuses to recognize as qualifying for the R&D tax credit.

Stock options are an important component of the compensation package for Apple's R&D employees. By providing this compensation structure, we are asking our researchers to invest themselves in the future they are helping to create. We are offering them company ownership.

The IRS should not hinder such progressive compensation practices by declaring them ineligible for the R&D credit. This is a short-sighted, destructive policy.

We applaud this Subcommittee's effort to focus the nation's attention on these important R&D tax issues so critical to our future success. We need and want stability in the R&D tax policy, and in its implementation. We need and want a permanent R&D tax credit.

But, Mr. Chairman, in addition to the fluctuating treatment of R&D in the tax code, current Government procurement policies actually provide a powerful disincentive to companies like ours. In practice, Government procurement policies tend to ignore innovation, retard research, and disdain the introduction of new technologies.

It would seem logical that the Federal Government, which is striving to create a climate that fosters innovation, would want to embrace that innovation by buying and using it. In fact, just the opposite seems to be true in some agencies, especially in the case of small computers, such as those Apple makes.

At the national level, the necessary policies for buying commercial, off-the-shelf products are in place. In actual practice, the field is not implementing this policy very rapidly.

The Government will continue to receive old technology as long as it continues to take several years to complete one grand design procurement action. Our industry is turning out new products every 12 to 18 months.

Another Government practice that acts as a disincentive to research and development and to the introduction of new technology to the Government, is the pervasive procurement practice of design specification writing.

Agencies tend to write design specifications that dictate the solution to a problem or need. Apple has been the victim of this type of restrictive spec writing from time to time. We look forward to new approaches that will ensure that every vendor is afforded a level playing field for offering its products to the Government.

When the Government ignores innovation and continues to buy old technology, what kind of signal does that send to our nation's creative innovators, who are out there working to fulfill a dream for better government and a better world?

For example, the United States Air Force is presently planning to buy over 200,000 desktop personal computers over the next four years, at a cost of what many agree will be over $1 billion. The winner of such a contract will likely lock in a 50 percent market share over the next four-year period for personal computers.

The Air Force fielded a design specific procurement document that reveals a very significant bias toward one proprietary technology. The Competition in Contracting Act requires full, fair and open competition. The Air Force, in effect, picked the winners and losers of this procurement not be price, not by functionality, but by design specification writing.

Functional specifications have been a requirement at the national level for many years now. In actual practice, however, their use is rare and wonderful. Compatibility is not the issue here. Our MacIntosh computers are designed to co-exist with virtually all computers found in the marketplace, but the Air Force procurement officials seemed to reject any approach that does not meet their narrowly defined view on these issues.

Apple Computer is being asked to retrofit ourselves to old technology as a prerequisite to serious consideration for Federal Government contracts. The obvious inconsistency here is that procurement officials are asking us to take a step backward to do something we are not designed to do or be, while policymakers are applauding our aggressive research and development efforts and the innovative products that result.

Clearly, this type of administrative policy does not fuel the entrepreneurial spirit of America's innovative firms to create solutions for our Government. A short summary of what we think needs to be done on this and the tax issues mentioned earlier, are outlined on the last page of our written testimony statement.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Poulos follows:]

Statement of B.N. Poulos
Apple Computer, Inc.
Presented to
Subcommittee on Science, Research and Technology
United States House of Representatives
May 18, 1989

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WHAT WE EXPECT FROM OUR GOVERNMENT

The United States has always been known for its inventiveness and ingenuity. Throughout history, we have been the engine for worldwide technological innovation and change. Our citizenry is stocked full of restless risk-takers and entrepreneurs with an unusual propensity to trade away the status quo in the hope of finding a better way.

The driving motivation behind research and development is an unwillingness to be satisfied with our present level of achievement. It is performed with a vision of optimism and hope for the future. Two college dropouts were not satisfied with a computer environment that forced the mass of humanity to submit to the high priesthood of the almighty mainframe. They dreamed of a machine that would bring computing power out of the inner sanctum of the central data processing backroom and into the homes and offices of the individual. Out of this dream came Apple Computer, Inc. and the birth of the personal computer industry.

It is important to state at the outset that we do NOT expect our government to provide the industrial dreams and vision for the future. We do NOT expect our government to provide the ideas for future research and experimentation. But we DO expect our government to provide a national economic environment which fosters creativity, vibrancy and vision. Our government must provide the fertile conditions wherein new ideas and technological ingenuity can flourish and come to fruition.

The current political and economic environment is fraught with problems which distract business leaders from their primary responsibility of providing industrial leadership and vision. For example, our industry needs a stable tax policy. In an international environment of rapid technology change, economic cycles, and foreign currency fluctuation, we should not also have to hedge our investment decisions against changes in the tax code.

THE IMPORTANCE OF A PERMANENT R&D CREDIT

But constant fluctuation has characterized the tax code in the 1980's. One example is the treatment of research and development. In 1981, Congress enacted the research and development tax credit to stimulate the increase of R&D nationwide. The credit helps to encourage technological change. It helps offset the pressure often felt from financial markets for short-term quarterly profits. The beauty of the credit is that it also gives companies the freedom to increase funding in research projects which it deems most appropriate. Apple is not interested in securing grants from the government for conducting research in specific technologies which happen to be in style. To survive in the fiercely competitive and ever-changing high technology industry, we must continue to allocate research and development spending in those areas which strategically position our company for business growth in the coming decades. The R&D credit facilitates this business flexibility.

But while research and development is a long-term investment, the credit has become increasingly a short-term policy. The initial credit existed for four years and then lapsed. It was then reduced in value and extended for three years. Last year, the credit was extended for only one year, and its value was reduced still further. It is now set to expire in December 1989. The objective of the credit--to make more money available for research and development--is admirable. But how can a company base long-term investment decisions on a congressional policy which cannot be counted on from one year to the next? Because rapid changes in technology and business conditions demand high levels of attention from our management, we can scarcely afford to concentrate on a "She loves me, she loves me not" congressional tax policy. A stable and reliable political and public policy environment is necessary to nurture an increasing amount of technological growth.

IN ADMINISTERING THE R&D CREDIT, THE IRS-PROPOSED TREATMENT OF EMPLOYEE STOCK OPTIONS DOES NOT REFLECT CONGRESSIONAL INTENT.

Stability must also be found in the administration of tax policy. Treasury regulations for the research and development tax credit are only now being re-proposed by the IRS seven years after the credit was enacted. In other words, the IRS is now attempting to define the rules for tax credit treatment eight years after the fact. In the absence of regulations, but in accordance with with the plain intent of Congress expressed in the language of the law, Apple Computer treated all wages subject to tax withholding as qualifying expenditures for the R&D credit if the employee was directly involved in the R&D process. The IRS is now telling us that one form of taxable wages, that of employee stock options, is a special exception and cannot be used for the R&D credit calculation.

In the years 1981-83, the period focussed on by the IRS, Apple was a much smaller company with only $300-500 million in gross revenues (as compared to almost $5 billion today). Stock options were then, and are still used by small high technology firms because they usually suffer from cash flow shortages despite a promising future. Stock options ease the liquidity crunch by offering a non-cash, deferred compensation to employees which can be redeemed at a later date. These options are granted in lieu of additional cash income. In fact, the only way small, risky companies are able to woo talented and high salaried employees from larger, more mature firms is by including stock options in the compensation package. While the small companies typically offer the recruited employees a smaller cash wage than the companies from which they come , the stock options represent a potentially large stake in the future. Thus, by raising this administrative barrier, ex post facto, the IRS makes the R&D credit discriminate against smaller high technology firms who use stock options much more than the older and larger firms.

It was during the 1981-83 years that Apple R&D efforts resulted in the creation of the Macintosh Computer, a product which now generates the largest share of our sales. It was the R&D team of creative technologists in this period that produced the easy-to-use graphics interface for which the Macintosh is famous. This is the revolutionary technical development that is now leading most of the rest of the personal computer industry to create graphics-driven interfaces for their own computers. It is the compensation of these R&D visionaries that the IRS, now nearly seven years later, refuses to recognize as qualifying for the R&D tax credit.

Stock options are a particularly important component of the compensation package for R&D employees of fast growing, inventive companies like Apple. Apple's future income stream comes from the products and technologies developed by our R&D team. By providing this compensation structure, Apple is asking our researchers to invest themselves in the future they are helping to create by accepting stock options in lieu of higher cash wages in the present. If the future products result in financial success for the company, these researchers stand to benefit greatly. If the future products fail and the company suffers losses, the stock options become valueless.

Employee stock options are a progressive, innovative approach to compensation. They offer company ownership to employees. They engender more employee concern over total corporate performance and product quality since their wages are directly connected to the success/failure of the company. They also represent a form of flexible compensation. In prosperous times, employees get a share of the corporate financial profits. In economically depressed times, employees share in corporate cost-cutting by accepting potentially valueless stock options.

Such wage flexibility can even enhance employee job security since compensation rises and falls with corporate revenues.

The IRS should not hinder such progressive compensation practices by declaring them ineligible for R&D credit purposes. This is a shortsighted destructive policy which the IRS now flaunts in the face of clear Congressional intent for the stimulation of research and development.

Apple and hundreds of other innovative companies like us have succeeded in the past. We have remained lean and agile, pouncing on new ideas, creating new products and seizing global markets. Our outlook is nothing but bright. But we too see clearly the bothersome indicators that signal an erosion of our nation's ability to remain the world's leading innovators. We applaud this subcommittee's effort to focus the nation's attention on these important R&D tax issues so critical to our future success. We need and want stability in the R&D tax policy and in its implementation. We need and want a permanent tax credit.

BARRIERS TO THE SALE OF INNOVATIVE COMMERCIAL PRODUCTS TO THE GOVERNMENT SEND AN INCONSISTANT SIGNAL TO THE R&D COMMUNITY

Nearly three years ago, Apple Computer opened numerous offices around the country to provide sales and service to the federal government. We saw a significant business opportunity to help the federal government be more efficient with its procurement dollars by introducing to them an easy-to-use, market-tested computer technology which has proven itself in the commercial workplace and in this nation's education institutions. With our easy-to-learn, easy-to-use technology, federal agencies can significantly reduce the time and cost of training their staffs. This ease of use translates to more productivity for the federal workforce, something we all hope to see happen in these times of constrained budgets. Our Macintosh has been and continues to be a great success in the commercial world.

Our Federal Systems group has been successful and has exceeded the company's expectations for growth, to a large degree because of the dogged persistence of our sales representatives. Doing business with the federal government is not like any other sector of the American economy. The truth of the matter is that our government's acquisition policies make doing business with the federal government very difficult, risky and costly. Fortunately, Apple has made a commitment to this market and intends to be successful in communicating our message of hope for high productivity tools for government employees and managers.

But, Mr. Chairman, current procurement policies are actually a powerful disincentive to a company like ours to invest in research and development of new technology. In practice, government procurement policies tend to ignore innovation, retard research, and disdain introduction of new technologies.

It would seem logical that the federal government, which is striving to create a climate that fosters innovation, would want to embrace that innovation by buying and using it. In fact, just the opposite seems to be true in the case of small computers. Actions by various departments of the government send clear signals that the government does not yet understand what is necessary for an American company to remain globally competitive and yet sell its products to its own government.

MANUFACTURERS OF INNOVATIVE COMMERCIAL PRODUCTS, WHO ARE COMMITTED TO STAYING COMPETITIVE IN GLOBAL MARKETS, CAN NOT AFFORD THE EXTRA COST AND RISKS IMPOSED BY THE UNITED STATES GOVERNMENT'S PROCUREMENT SYSTEM.

Much federal procurement policy today is based on the concept that "fair and reasonable" contract price can only be assured through the burdensome and intrusive examination, audit and regulation of the financial books and business practices of private commercial firms. If firms are paid by the government to research, develop and build such unique items as ships, tanks and planes, solely for government use, some degree of close examination may be necessary. But for companies who development and manufacture commercial products, solely at their own expense, without federal funds of any kind and primarily for world-wide commercial markets, to reveal cost and pricing data to the government is tantamount to giving it away to global competitors. The result of this intrusive practice by some contracting officers results in some companies refusing to sell to the government, even when they have won competitive bids, because they cannot afford to reveal business confidential data.

U.S. procurement policy today is an intricate and frustrating web of complex regulations which, on the whole, fundamentally rejects economic principles of free markets and robust commercial competition. As the Packard Commission so accurately points out, the U.S. Government frequently buys old technology, pays too much for it, and seems to avoid the advantages of proven, off-the-shelf commercially available technology. The Commission also made strong recommendations for a streamlined procurement system for the timely purchase of commercial products. If a product like our Macintosh computers can withstand the rigors or commercial competition, you can be sure that any "fat" in the price has been squeezed out, and the product has stood up to the marketplace race.

THE LENGTHY PROCUREMENT PROCESSES FREQUENTLY RESULTS IN THE PURCHASE OF OLD TECHNOLOGY

At the national level, the necessary policies for buying commercial products are in place. In actual practice, the field is not implementing the policy rapidly. The cumbersome and lengthy procurement process used to purchase products was originally designed for the purchase of custom-built products for government and especially to military specifications. Using the old fashioned, cost-based contractor procurement system for buying off-the-shelf commercial products is a waste of procurement talent. Although commercial products are widely recognized as offering significant cost and performance advantages, the procurement system has changed very little over the years to speed those commercial products into the hands of government employees. This is especially true in desk-top computers such as those Apple makes. The government will continue to receive old technology as long as it continues to take several years to complete one large "grand design" procurement action. Our industry is turning out new products every year to 18 months. So you can see, the day the government award is made to a winning bidder, the product is likely to be less than leading edge technology, if not completely obsolete. GSA is aware of the problem and has some interesting data on the obsolescence of the government's information systems.

THE CONTINUED USE OF NARROWLY DEFINED "DESIGN SPECIFICATION" DEPRIVES THE GOVERNMENT OF THE BEST SOLUTIONS TO ITS NEEDS.

Another government practice that acts as a disincentive to research and development and to the introduction of new technology to the government is the pervasive procurement practice of "design spec" writing. Instead of the government agency asking that commercial industry use its best minds to provide solutions to a specific problem or need, the government tends to write "design specifications" that dictate the solution to the problem or need. This practice retards research and development and the introduction of new technology to the government. Apple has been the victim of this type of restrictive spec writing from time to time, and we look forward to new leadership and to new approaches that will insure that every vendor is afforded a level playing field for offering its products and services to federal agencies. When the government continues to buy old solutions, what kind of signal does that send to our nation's creative innovators who are out there working to fulfill a dream for a better government and a better world?

For example, the United States Air Force is presently planning to buy up to 240,000 desk-top personal computers over the next four years at a cost of what many say will be over one billion dollars. This procurement is particularly important because other federal agencies will likely buy off the contract once it is awarded. The winner of such a contract will likely lock in a 50% federal market share over the four year period.

The Air Force fielded a design-specific procurement document that reveals a very significant bias toward one proprietary technology. The Competition in Contracting Act requires "full, fair and open competition." The Air Force, in effect, picked the winners and losers of this competition, not by price or functionality, but by design spec writing. Functional specifications have been a requirement at the national level for many years now, but in actual practice, however, their use is rare.

THE "ONE-SIZE-FITS-ALL" MENTALITY IN SMALL COMPUTER PROCUREMENTS LIMITS INTRODUCTION OF INNOVATION AND HAMPERS USERS.

The Air Force has authority to exercise flexibility by allowing more than one kind of microcomputer to be purchased by Air Force personnel for their varied requirements. If this department's strategy in buying desk-top computers were also applied to the procurement of aircraft, the Air Force would be buying one type of obsolete fighter aircraft for every type of flying mission. As it pertains to small computers, this "one-size-fits-all" approach is not a cost effective solution to the Air Force's varied microcomputing requirements. The true life-cycle cost of this narrow design-specific approach will result in greater training costs and less than optimum productivity.

Compatibility is not the issue here. Our Macintosh computers are designed to co-exist with most all computers found in the marketplace. There is no technical barrier at issue here. But the Air Force procurement officials seem to reject any approach that does not meet their narrowly defined views on these issues.

There seems to be more interest in maintaining backward compatibility with the older installed base of computers, merely for the sake of uniformity, than in buying easy-to-use productivity tools. Moreover, Apple Computer is being asked to retrofit ourselves to old technology as a prerequisite for serious consideration for federal government contracts. The obvious inconsistency here is that procurement officials are asking us to take a step backward, to be something we are not designed to be, while policy makers are applauding our aggressive approach to research and development and to the innovative products that result. Clearly, this type of administrative policy does not fuel the entrepreneurial spirit of America's innovative firms to create solutions for our own government.

In 1984, Congress enacted the Competition in Contracting Act to set forth new policies for government buying practices. The Congress recognized that robust competition by large and small firms alike would provide the government with its best assurance of fair pricing, quality products and leading edge technology. Instead, contracting officers and agency leaders are continuing to rely on heavy regulation and design specification writing as the core of procurement policy. Reform in this area must be a high priority for this legislative body in order to create an environment that fosters R&D, innovation and creativity which our own government can use..

In summary, let me clarify just what we think needs to be done :

1. Enact a permanent R&D tax credit.

2. Cause the Internal Revenue Service to administer the R&D tax credit so that predictability and stability will result for America's R&D community. We believe that Congress needs to clarify and reinforce its original intent to treat all R&D compensation subject to tax withholding as a qualifying expenditure for the R&D credit.

3. Implement the Packard Commission's recommendations for reform of the procurement system that will remove the impediments to commercial product procurement and institute a streamlined procurement system that insures full, fair and open competition for vendors.

4. Require through constant congressional oversight, that GSA more carefully execute it's responsibility for insuring compliance with the Competition in Contracting Act, so that agencies cannot continue to masquerade their bias in proprietary, "brand name or equal" contract specifications.

5. Eliminate the costly and unnecessary Cost and Pricing Data audits and certifications for products that clearly meet the requirements for being commercial products.

6. Initiate a requirement that the full life-cycle cost of products be considered in government purchases. If all costs of training, supplies, and the costs of maintenance are considered in purchases, then durable products will be encouraged and rewarded.

7. Foster more direct consultation between vendors and end-users of products so that procurement specifications will be written around the uses and functions of the product required. In government, the people who buy products are not the same ones who must use them. This is a departure from the commercial market where consumers have a strong say in what works.

Mr. **Hayes**. Thank you very much. Prior to beginning questioning, I see that Congressman Mineta has asked that this be inserted in the record with his opening statement. I don't really know, I may have to take this under advisement for some time. Maybe just this once.

[Laughter]

Mr. **Mineta**. Mr. Chairman, about the highway you were asking me about yesterday—

[Laughter]

Mr. **Hayes**. We would be delighted to insert this opening statement.

[The prepared statement of Mr. Mineta follows:]

MINETA

Thank you very much, Mr. Chairman.

I must admit that I feel a certain sense of deja vu about this hearing, and the feeling is not a comfortable one.

More than 5 years ago, I testified before the Ways and Means Committee on the need to permanently institute a meaningful R&D tax credit. Five years later, nothing has changed.

The rites of renewal for the R&D tax credit have become as predictable as fireworks on the Fourth of July. We keep extending it and extending it -- but we never make it permanent. Well, what are we waiting for?

The United States leads the world in basic research and development. But our percentage of civilian R&D has been sliding for years, and I maintain that the uncertainty of the tax credit year in and year out has contributed to this slump.

If the U.S. is going to take a strong, consistent lead in technology and competitiveness, then we must have a permanent research and development credit so that our businesses can make the informed, long-term decisions they need for their R&D programs.

Our industries want to compete in the international marketplace, and they know they can win out. We know that, too. So it seems to me that it's high time that the Federal Government gave our industries a clear signal that the commitment to R&D is genuine and will endure year after year.

Thank you, Mr. Chairman.

Mr. Hayes. Briefly, because I'm sure there are other people who wish to ask questions ...

Dr. Caulder, you made a comment earlier. I want to make sure that I understood it. In a previous life, I used to do some tax work. You made a comment about the impact on small business competitiveness of changes in capital gains law. I assume that the competitiveness that you are talking about is in the area of stock options and the area later touched on in some of the ESOP arrangements—is that correct, or is there an additional area that I did not hear?

Dr. Caulder. No, it's in stock options. We pride ourselves in hiring bright people, and once they figure out that all we're doing is delaying their income now by giving them stock options, they ask me why. It's hard to explain to them.

Mr. Hayes. I'm also curious—we feel a consistency in the testimony that we get. I know that you probably have felt that you come into a hearing—you've got a half dozen people—you wonder, in a body of 435, how that information spreads. The fact of the matter is that the groundwork laid does. I used to think when I got here that it didn't much matter what was inserted in the record. There are indeed both dedicated staff people who look at it and something you learn from each one of these hearings.

I know that you mentioned and specifically talked about tax incentives. Tell me in the context though, more specifically if possible, what—whether it's in the field of tax, whether it's in the field of credits, whether it's in the field of deductions, whether it's in other Government proposals—what priorities of Government action would have your company do things in research and technology it might otherwise not do? What would most urge you to cross a barrier which, within your own board of directors, is marginal now, but in light of some Government action, impetus or tax advantage, would push it to the other side? Is that list the same, and if so, in what order of priorities, for your company?

Dr. Caulder. When you're in a very small company like we are, we only have about 150 people, and when you're in a very new science, into which you are introducing the pioneer products, you can't look at any single thing and say that "this will make me make a decision differently."

The things that make me make different decisions, and the three points that I pointed out, the alternative minimum tax, capital gain and the R&D tax credit, those have a very, very severe impact on me attracting the talent I need in order to accomplish some of the scientific barriers that we have to go through in order to get these new biological pesticides invented and in the marketing place.

So, to look at a tax problem right now and what it does is inhibitory in the real bowels of the company and those are the people I can get, rather than saying I would do a research program differently, as in Apple Computer would, obviously they have products in the market place and they have income.

I don't have any income now. Mine's all outgo. I just spend money. I've got a lot of shareholders that would like me to change that. I can't change that without the right kind of people, and the things I outlined inhibit me from getting those people now.

I have several vice presidents that I recruited out of large companies with the promise of "you're going to own part of this company, and through capital gains you're going to be able to increase your equity and your net worth over hard work over the next five years." The alternative minimum tax change and the capital gains tax changed that.

In effect, I recruited these people with a promise I couldn't fulfill, with something I have no control over now. I need to recruit other people to do that. I can't do it now.

Mr. **Hayes**. This leads me to Mr. Swihart. I appreciate those observations from the standpoint of industry demand, with Mr. Swihart having an opportunity in recent years to look at production—for the product that you need, for the bright people that you need in your business.

We have a Government that has retreated from its commitment to funding of graduate work. To what extent has your experience in industry shown a picking up of that previously committed burden and to what extent do you attribute a shortfall? And, briefly outline if you could the approaches that we might take—you heard the academic panel a little earlier—from your present experience, the approaches we might take, and your priorities, and what we could do to help fill that gap. But, first of all, what has industry done? What's been the response?

Mr. **Swihart**. Mr. Chairman, I think that industry, in particular, my own previous company, supported the universities very heavily. We just recently gave the University of Washington another $5 million. We've given half million dollar grants to a lot of the major technical universities, some represented by people on your committee, close at hand.

Now we do provide any student, any employee who wishes to get a masters degree, we provide him with full coverage of his tuition as long as he maintains B or better, overall. I think the industry as a whole is supporting the universities, but we still need more of those bright, young people to come from the K through 12 into college, into the masters, and on into the doctorate degree. Some of the things that Dr. Liebman said I think we could support very wholeheartedly.

Mr. **Hayes**. Thank you. Mr. Poulos, I'll make an observation that will make you feel better. When I first got here, I wanted to purchase equipment for our Congressional office, and I found that, on the allowable list of items I could purchase, was equipment that cost twice as much as what I could buy that worked better, but it was already on the approved list. Whereas, if I waited for other items to get to the approved list we would have a telephone only—for the year or so that it took for them to consider whether improvement had been made. The same thing is true of our telephone system.

One of the things that Government does worst is, in trying to do the right thing and preventing someone from having an unfair advantage or someone buying equipment from their brother-in-law, we end up making rules that avoid that—but unfortunately, we can't buy equipment from anyone else either.

In light of that, I can certainly, sympathize with your comments about procurement. From the example I gave, we have some control over it. From the agency level, I would be interested in knowing your comments, because yes, there is oversight. In the example used it was the Air Force. Sure, there is oversight within armed services, but once again, the time delay of oversight is one that allows them to address a previous circumstance, rather than anticipate the manner in which they could perhaps urge action.

So from your previous statement, what do you do in advance? What do you do as an oversight committee in armed services or in hearings like this to formulate what anticipatory actions we could take, rather than having to deal with what's described as a previous dilemma and have to work in the aftermath of what's already done?

Mr. POULOS. A company like Apple opens offices around the country to do business with the Government in a positive, effective way. It does not want to establish an adversarial relationship with agencies of the Government. When we find these kinds of procurement biases, we try to work directly with those agencies first to educate, and to market our product.

We have an education job to do, and we're doing that. But when we find the biases that run as deep as we've seen evident in this Air Force procurement to which I made reference, we can only go to the leadership of that agency and call their attention to the problem, which we have done in this case, I might say. Our voice was not heard.

What's left to us?—to come to you and ask for oversight of this and of future procurements. As I say, I think the proper statutes are in place. We don't need more law. What we need is a clear oversight by the General Services Administration to ensure that the provisions of the Competition in Contracting Act are in fact enforced, and that in this case, through a document called a delegation of procurement authority, the Air Force was given authority to conduct this procurement. But who looked at the procurement to see whether it was truly full, fair and open?

So the only thing we can do is communicate directly with the agency and then, if that doesn't work, of course, with committees with oversight jurisdiction. That is why we bring this issue to you, in the hope that you will highlight what we believe is a significant bias in Government procurement.

Mr. HAYES. Thank you very much. In light of the time, though I really do have several things I would like to go into, I would rather defer to the Chairman, Congressman Walgren for questions.

Mr. WALGREN. Thank you Mr. Chairman. I want to salute Congressman Hayes' interest and background in this area. This hearing is in large part framed around his contribution in developing it. So I want to express my appreciation to you, Congressman Hayes, for helping with this hearing.

Mr. HAYES. If the gentleman would yield, I certainly didn't invite Norman [Mineta] to it, though, when we were talking about it.

[Laughter]

Mr. WALGREN. What kind of instinct do you have for the R&D tax credit as opposed to other kinds of financial incentives or barriers that you've dealt with in private industry? The comment was made that the R&D tax credit doesn't really rise to the level of boardroom decision in companies making a commitment to pursue one thing or another, but rather is used as an after-the-fact bit that is handed to the accountants when they are told to reduce the tax liability of the firm to the most proper extent that is available.

Can you give us any feel about how the R&D tax credit would compare with investment tax credit or other kinds of treatment that would be helpful?

Mr. **Swihart**. I might address that, Mr. Walgren. I think that each one of those things that you mentioned get just about an equal amount of weight. Whenever you're doing a billion dollars worth of research and development a year and you don't know whether or not you're going to get a 20 percent investment tax, or 10 percent investment tax credit, or 5 percent, or 20 percent R&D credit, the next year, you look very seriously on those particular kinds of decisions, as you project your future.

Because, obviously in our business, like others, you must project in the long term. You have to be doing five and ten year planning into the future. So I don't think there is any great differentiation between those except that we do need continuity and we do need to know that they are either not going to be in place, or they are going to be in place so we can do adequate planning on that basis.

Mr. **Poulos**. I would like to echo his comments. Nothing goes to the bottom line faster than the R&D tax credit. The initial decisions to invest in a new technology are basically technological decisions based on the feel that our people have for the probability of success.

But ultimately, whether that effort is funded by the company is a financial decision. The degree to which we can count on the R&D tax credit then of course provides that support. If we can't count on it, if we don't know whether it's going to be there next year and the year after, then it erodes that support.

Dr. **Caulder**. I would agree wholeheartedly with both those statements. I would like to make a more general statement about R&D funding. I made a comment that I think we have a basic problem in the United States. We no longer have a population that can really separate science from technology.

The thing that disturbs me from a small-company standpoint is that when I rummage around in basic research looking for something to convert to technology, that basket is getting too small. We are not funding enough basic research in the United States at our university level which is going to lead to getting good scientists, incidentally.

It goes back to—again, I'll repeat my father's statement—it's not by coincidence that as our science student population goes down, our MBA and lawyer population is going up. Those are the wrong priorities, as far as I'm concerned. So I'm very disturbed that the Federal Government is not stimulating enough basic research.

Believe me, if enough basic research is done, the Apple Computers of the world and the Mycogens will take that basic research and convert it to the technology that's going to create the jobs and the products that we're all looking for here.

But when I see our basic research eroded over time, and I'll give you one specific example as to one I have seen. In the 1940s, about 80 percent of our R&D budget went for agricultural research. Less than 2 percent of it goes for agricultural research now, and we haven't had an increase in constant dollars since 1968 in the agricultural research budget in the United States. That's very disturbing. We are now consuming our seed corn. We're not going to have anything for the future unless we change that.

Mr. **Walgren**. Interestingly enough, only yesterday, the Deputy Undersecretary of Commerce sat right in the chair to your left and in response to questions which I asked about preparation for going into the European markets in 1992, I received comments instead concerning the historic relationship where Government and business in this country were not as interactive as they are in the Pacific Rim, and the concept that that need not be overly disturbed.

The point I was trying to make you've just made much better than I attempted to yesterday. I admit that there is a distinction, both through culture and circumstance, that no, we need not repeat the Pacific Rim, the Japanese interrelationship of business and government. It doesn't mean that we have to change what is historically the distance that the majority of people in this country put there, but we do have to create an alternative.

The alternative linkage, as you've suggested, is through the university system, and the linkage has to, nevertheless, be made. Although it's different, it's nevertheless responsive. And, although it's an alternative to what might contain features that both have advantages and disadvantages, it still has to occur.

Instead, what we get in budget requests, and what we get in initiatives are not that. Initiatives and budget requests will simply say that private industry can pick up any of the gap that's made here and create both the pool of scientists and educate them and take them into industry.

What you're telling me is, that's not so, that the commitment of Government is a real one, and it is not in based on the historic separateness, but instead filled with what is a simplistic view that this Government has to do what individual people or companies cannot do only and solely for themselves.

What you then have to have is a small business erosion of opportunity to where only very, vary large companies are able to effectively create a system of supply and demand for the employees that need the technology to use.

I gratuitously offer that, but you can imagine a bit of our frustration when we're trying to make those same points to people who can do some initiatives through the Executive Branch, and who in turn think we're saying something else, that we want to change the historic structure and tell business what to do.

Instead, I suggest that in future correspondence and hearings and opportunities, suggest some initiatives that come not only from the legislative branch, but also from the Executive Branch of Government that don't destroy any of those traditional separate areas, but further, certainly further, economic opportunities for this country, and certainly further what the chairman of this full Committee likes to call the new wealth in technology, the full production of it.

I thank you for your observations. I didn't mean to take up so much time, but it's important somewhere that that be said, too, much as you said that it is sometimes important to make those cases after they are done.

The gentleman from California has—all right. Why don't I instead recognize the gentlelady from Maryland?

Mrs. **Morella**. Thank you, Mr. Chairman. I appreciate the testimony that I heard, and I want to ask you candidly what your appraisal is of a bill that many of us are co-sponsoring that would make permanent that R&D tax credit. It's H.R. 1416. Because in listening to your testimony, you are asking more than for making permanent the R&D tax credit, and I wondered if you had had an opportunity to look at the bill to give us your assessment of it? If you have not, I'm going to ask for the record we get copies to you and you send in your comments.

Dr. **Caulder**. I have looked at it. I put it in a category of "we'll take anything we can get." There are so few. Understand that all of us have probably overemphasized the R&D tax credit simply because it is a very visible thing, it is something that has been very capricious in how we've looked at it, in how we have been able to use it, and it has interfered greatly with our long-term planning.

So, there are many, many ways that I think you can incentivize small businesses and this conversion of our basic science to technology. That's just one component of it.

Mr. **Poulos**. I'd like to say that Apple supports that bill, primarily for two reasons. One, that it will be made permanent, that's what I understand the bill says. Two, that it will now include start-up firms, such as Mr. Caulder suggested.

We have 9,000 software companies that have grown up around and with Apple, small business, two, three or four people operations, that are writing innovative software that runs with our hardware. Those people need the advantages of an R&D tax credit early on, before they begin putting their product out on the market for sale and before they can start bringing the income in. We believe that is a critical part of the bill that we fully support.

Mrs. **Morella**. Incidentally, I just figured out that byte of the Apple, is that b-y-t-e, is that right? I just wondered—Mr. Swihart, did you want to comment on that?

Mr. **Swihart**. Mrs. Morella, NCAT is a 501(c)(3) corporation, and therefore we cannot comment directly on the bill. As an individual, I will tell you that I am very supportive of the bill, with hopefully, a few additional things.

Mrs. **Morella**. Dr. Caulder, you talked about basic research and the need for us doing that. It just seems to me from my limited experience that we are making some enormous progress and strides in basic research. But then we don't carry it to the technology point. That's exactly what other countries have done, like the Japanese. It seems to me that there is where there is probably a larger gap. Would you agree, or dispute that?

Dr. **Caulder**. I think there are two components to that. One, we seem not to do that. I think we have done that. But, again, I'll go back to—you don't create value by doing mergers and doing deals. You do it by making products.

And we tend to, at the basic level, sometimes trivialize basic research. I'm sure in 1896 when the electron was discovered no one ran into the streets and said "we can now have television." And I'm sure in 1972 when we spliced the first gene, that had Senator

Proxmire known about it, because the title was "Sex Life of Bacteria," he would have probably given it a Golden Fleece award.

So we can not anticipate what the need is going to be for basic research. And yet, if people can't come before you and say this is what I'm going to be selling in X number of years and how many jobs I am going to create from it, you cannot fund it. We can no longer do that. We have to support basic new knowledge. Believe me, if it is useful, it will get converted into products by someone like the Mycogens or the Apples of the world.

That basket is just running dry on us, though. It will get converted.

Mrs. **Morella**. This leads me to a question. At what level and in what way does that R&D tax credit become a factor in a corporation making a decision about whether or not to fund an R&D proposal? Is it important?

Dr. **Caulder**. It's very important, and I would disagree that it does not get to the board level. It depends on the size of your company. What bathroom tissue we use sometimes gets to my board level.

So when I look at the R&D tax credit, it is a matter of funding, and if you do the arithmetic, you fund those things, you think you have the highest degree of success, and you weigh that against the long-term risk. We have very few real long-term projects that go past three or five years. I would have more, though, if I had the ability to know that I was going to be financed over a longer period of time, probably.

Mrs. **Morella**. You've all mentioned in some way the procurement system—we don't need any more regulations, we need to clean them out, and we need to move faster. That seems to be a critical element, the speed, or the lack of same, which gives anachronistic stuff that we're buying because of the time lapse. You mentioned that in your testimony, Mr. Poulos.

You also talk about implementing, as a result of that, the Packard Commission's recommendations for reform of the procurement system. Are those recommendations adequate? Secondly, let me go into the same area. There is something I don't quite understand. It says "require the GSA more carefully execute its responsibility for insuring compliance with the Competition in Contracting Act so that agencies cannot continue to masquerade their bias in proprietary brand name or equal contract specifications." What does that mean?

Mr. **Poulos**. Those are pretty strong words, I know. The GSA has a responsibility to issue a delegation of procurement authority to an agency who wants to do a major procurement, such as the Air Force procurement I spoke of for over 200,000 units of microcomputers. Not just for the Air Force, by the way, it's expected that many agencies of the Government will buy off that contract once it's awarded, not just the Air Force.

If the General Services Administration were to properly exercise its responsibility in overseeing and delegating that procurement authority, it would check to insure that the procurement is in fact full, fair and open, not sort of fair, not kind of fair, but really fair to everyone.

When an American company based in Cupertino, California, with a plant in Fremont, California, makes an American-made computer with American technology, protected with American patents, cannot bid on a United States Air Force contract by virtue of the way the specs were written, then something's wrong.

That's where I believe that there was no proper oversight. I don't believe that the Air Force should be allowed to buy a billion dollars worth of microcomputers and not even consider Apple's offering.

Mrs. **Morella**. What can we do about it? You said Congressional oversight—Do you feel Congress has not been aggressive enough in pursuing reforms?

Mr. **Poulos**. The Government Operations Committee has been very aggressive on these issues. We look forward to their continued interest.

Mrs. **Morella**. You've had an opportunity to testify before them?

Mr. **Poulos**. We have not as yet, but we would certainly entertain an invitation to do so.

Mrs. **Morella**. The Office of Technology Assessment has given pretty—well, I think they lack personnel themselves, but they haven't given very good grades to the whole procurement process in terms of testing, in terms of competitiveness, and evaluation. Would you tend to agree that that's been one of our major problems?

Mr. **Poulos**. I won't comment on that, I will just say that there is an ongoing investigation right now in the Government on procurement bias in the area of computers. We merely ask that a look be taken, that when a major corporation like Apple comes to work with the Government and be a good business partner, to be shut out of a major procurement like that just runs across everything that's American to include fairness.

Thank you.

Mr. **Swihart**. Mr. Chairman, this is a very good example of something that was one of the strong recommendations of the Packard Commission. The Packard Commission recommended that the Government use more commercial practices and in this particular case, I think quite clearly if they were using commercial practices and getting rid of the many, many yards of specs that there might be a different answer.

Mrs. **Morella**. Could I just ask one small further question, Mr. Chairman?

Education—you've all mentioned that education is important, you talked about math illiteracy, scientific illiteracy, but then looking beyond that, you would talk about just the ability to communicate, to understand not only the English language, but then to have a facility perhaps through our schools for other languages which will help this competitiveness.

How do you go about doing that? Elementary school is obviously important. I think it's more important than when you reach the higher education, because our students are going to go into higher education in math and science and engineering if they are given the incentives and the excitement early on.

But you're not just talking about math and science, you're talking about across the board. Now, how do you get the best teachers that are going to inspire others? Is it money? Would you make it special so that you just give special compensation to teachers in critical areas? What would you do? Mr. Poulos, would you comment on that?

Mr. POULOS. Apple has many programs along those lines. We are the leading computer vendor to schools and universities around the country. We sponsor programs to reward young, innovative software writers, for example. Apple has a close relationship with educational institutions. It has for its entire history.

One of the things that the computer industry has done, though, that I think is remarkable, is that it has over the years provided computer products to students and faculty alike, at very, very deep discounts. We know that students don't have a lot of money to spend on fancy computers. So we really cut the margins thin to offer these products through university bookstores.

It's distressing that the Ways and Means Committee is now considering a tax which would increase the cost of those computers to those students. It would disallow those low price products to professors. It would impose a tax on the unrelated business income generated by that bookstore.

We think that these kinds of actions send the wrong signals. We want to put tools in the hands of students and professors alike so that they can learn to work and think better than they do today. We think our technology will help them to do that.

We're willing to invest in the future by really trimming the margins down and providing these products to students and faculty at very low discount prices.

Dr. CAULDER. I think like most things, you work for incentives. Incentives can come in many forms, but I can assure you since the Phoenicians invented money, thanks comes in second. We have to reward people for what they do. You do that through an incentive system that allows them to work toward their particular goals. Money is always one of them.

I have been on a couple of curriculum committees at universities and a question I get that always bothers me is they want to know how we can train our science students to get into biotechnology. I think our universities have drifted too much into a training mode rather than an education mode. I am tired of getting Ph.D.s that can't write a simple declarative sentence.

So I think that we have to start very early, in fact I would recommend a book to all of you, it's called "All I Really Need to Know I Learned in Kindergarten," and it has some very poignant points in it. We have to start early, and we have to keep educating our populace, rather than continuing to train them in a technology that's going to be outmoded.

To give you a specific example, six years ago when we started Mycogen, we needed molecular biologists. There weren't any. We had to retrofit biochemists to become protein chemists. It wasn't too hard to do when we found a good biochemist.

Everyone wanted to train protein chemists. I don't need protein chemists anymore, I need fermentation chemists. There aren't any of those now. So if you try to train for a particular skill, you're always going to be behind. We have to continue to give a broad education to all of our students, so that they can be trained when they get to industry. The university is no place to train students, it's a place to educate them.

Mrs. Morella. You have a very good point. It's like when Edwin Arlington Robinson in one of his cynical moments in writing poetry said "all the world is made up of kindergartners trying to spell God with the wrong blocks."

Thank you, Mr. Chairman.

Mr. Hayes. Thank you. Now, if there is anyone, because of the length of the hearing that needs to go stretch, go outside, or perhaps to the restroom, now would be a good time, because I'm going to recognize Mr. Mineta of California for his questions.

[Laughter]

Mr. Mineta. Thank you very much, Mr. Chairman, I think.

First of all, let me thank the panel for their contributions on this subject matter. As you are familiar, the American Electronics Association is in town this week with their Capital Caucus. Their main emphasis has not only been the R&D tax credit, but has really been more on the cost of capital, the availability of capital, and the difference between the cost of capital to a new company like Dr. Caulder's firm, an existing company like Mr. Poulos'—but in any event, the cost of capital and the difference between, let's say, a Japanese company and a U.S. company.

In terms of the order of priority, and given the importance of R&D tax credit, educational tax credit, things of this nature, where would you place cost of capital, R&D tax credit, all these other things that we have to deal with, given the fact that today the name of the game is income to the Treasury. As soon as you say "tax credit" someone will say, "holy cow, that's a loss to the federal coffers." We get a lot of knocks just on that basis. Yet, there are a lot of us who are supporting these various kinds of tax credits, including an incentive of the old investment tax credit.

The investment tax credit, from my perspective as a former chair of the Aviation Subcommittee, was the biggest thing that we needed to get airlines to invest in new equipment. Where would you place it, in terms of a priority listing, as to what we ought to be doing?

Dr. Caulder. I would place cost of capital right at the top. Because since the October crash of a few years ago, equity capital is no longer available to small companies, so that means that your capital is now more expensive that it has ever been before because you end up selling your technology to someone. That's the way you raise capital.

Mycogen's specific example has been that we have two rather large deals with Japanese companies, and we've had to form limited partnerships with Japanese companies in order to raise capital. So in a small company, cost of capital and what you have to give up for it is very, very expensive now.

Mr. Mineta. But the alternative is long-term debt, and do we have that kind of capability to have long-term debt financing?

Dr. Caulder. I'm not sure I understand exactly your question.

Mr. Mineta. First of all, we have to have a savings pool in order to have, either a capital available through either equity funding or through debt funding. We don't have the savings rate that Japan, West Germany, France, Britain, seem to have. So we are sort of behind the eight ball right from the beginning because of the difference in savings right now. As I recall, the figures are somewhere about four percent savings rate for U.S., whereas the savings rate for the Japanese is somewhere around 21 percent to 22 percent, West Germany, 18 percent to 19 percent. I'm just wondering whether or not we go to debt financing or to equity financing, whether we really have a capital pool without having to go to foreign sources.

Dr. **Caulder**. Well, again you've touched on what to me is a personal sore point. We get back to we've been rewarding the wrong things. We reward people for leveraging themselves rather than saving. We tax our savings accounts and then we allow people to leverage themselves and give tax breaks on debt. That's the wrong priority, as far as I'm concerned.

So as long as we have that system, we're never going to have the capital pool going into savings that we can draw on at the low interest rates the Japanese have, for instance. They save a significant portion of their income, and they only get three percent return on it. So there is a lot of capital available for the Japanese companies in order to expand their business or start new technologies. We don't have that same one to draw on.

Again, the public market is gone for small companies. There is no equity market now in our area I don't know of any company that has had an initial public offering or has had a secondary in quite a long time. You have to do what I have done, which is go to other sources in order to get it, and the only assets we have in a small company are intellectual assets. We have patents, and intellectual assets, the banks don't loan you a lot of money on that.

So you've got to convince someone else that they have value and those people that you convince they have value are the people who recognize it as a long-term investment.

The other eight ball that we're behind, when I discuss with my Japanese partners their outlook, is very simple. They say it's very easy for them to dominate an industry. They look at an industry, whether it be electronics or biotechnology, and they say we would like to read your annual reports, because your CEO says he is going to have a certain return on capital, return on investment, on a quarterly basis. He says, if he sets his at 15, I'll set mine at 12. He moves his to 12, I'll move mine to 8, because I know I'm going to be in my job 20 years. He's going to be gone in two. That's the type of mentality we're dealing with in the capital market, and that's why it's very lucrative for small companies with long horizons for products to turn to that market to get their money. It is very expensive, though. I had to give up half of the Asian market, in a joint venture, in order to raise capital.

Mr. **Mineta**. Should we disallow interest, then, to a company for the junk bonds?

Dr. **Caulder**. Again, the ability of a small company to participate in that type market just isn't there. It's not available.

Mr. **Mineta**. Given the fact that we're faced with maybe the possibility of having, to in order to get away from the LBOs and the kind of mergers that seem to be going not for expansion purposes but for downsizing purposes, every major merger we've had, the companies have had to sell off assets in order to be able to keep going. KKR—on the RJR, the Reynolds acquisition, Nabisco—now they're selling off Nabisco and Del Monte and all the food products in order to finance the purchase of R.J. Reynolds. Should there be a disincentive by disallowing the ability to write off the interest cost in those kinds of deals and try to get into something more productive, R&D tax credits, or university R&D tax credits, or some other area? Sematech— there are all kinds of innovations going on.

Dr. CAULDER. I'm not a real proponent of having disincentives. Give incentives. Make it so much more valuable to do other things with those assets that it doesn't occur to anyone to provide disincentives.

Mr. MINETA. We have those incentives right now in the tax laws. That's what created the junk bonds and what do we get out of it? We get a sharp stick in the eye. I've seen so many companies, just in the airline industry be destroyed by this.

Dr. CAULDER. It's an incentive for doing a deal, though, not creating value.

Mr. MINETA. Value, you are absolutely right.

Dr. CAULDER. And it's wrong incentive.

Mr. MINETA. So why not do away with that incentive that's there, and disallow the interest cost on those junk bonds for these people who are tearing us apart, rather than trying to build something for our future?

Dr. CAULDER. Exactly. To me, it's just like capital gains. I don't think we ought to have capital gains on a lot of things we had them on in the past. But do have capital gains on people who truly have an equity investment and are willing to hold it for one or two years, or three, whatever the amount may be. That's a true capital gain then. A true capital gain isn't when you're dealing real estate and flip it.

Mr. MINETA. You're absolutely right. Mr. Poulos, any comment?

Mr. POULOS. I think it's fair to say that cost of capital is, if it's not the first, it's certainly the second priority within our company, although Apple abhors long-term debt. We don't have any, have not had any. Cost of capital is a structural issue that either helps or doesn't help us remain competitive. Certainly, when I say either the top or the second place issue with us, equally as important, is market access to foreign markets.

Mr. MINETA. The comment you made in your statement about design specifications is so apropos because I think in all of Government, we're too design specific. We ought to be performance standard based, and yet performance standards really aren't the way that most RFPs are let around here. Until we get away from being design specific, I think you're going to find that problem over and over again. We do have the Contract Compliance Act that was passed—I believe in 1983—in terms of fair and open contracting. But despite that the agencies are design specific. That may be the difference between the ins and the outs.

I remember when we did the computer tax credit to companies that gave computers to educational institutions. I don't know how many IBM people I was visited by that said "This isn't the way to go. This is an Apple bill." That was a specific comment to fight what we were doing in terms of that computer tax credit that was worked on. But then again, it's just the outs versus the ins. We see this all the time.

Have you made any progress on this performance standard versus specifications?

Mr. Poulos. With the Air Force, no.

Mr. Mineta. What about GSA?

Mr. Poulos. We're communicating with GSA now on the issue, not just with the Air Force, but in a broader sense, and we believe we're going to have some success. As I said, we have opened offices around the country to market and to educate and to tell the Government about our product, and we're being enormously successful.

The Federal Systems Group, managed by Mr. Lloyd Mahaffy, has exceeded every target the company has set for growth in the past three years. Our sales are increasing at a very nice rate, and the leadership of the company is very pleased with the performance of that particular group in doing business with the Federal Government. So I'm not here to say that nobody's buying our computers. They're buying them faster than we every dreamed they would.

If customers and users in the Government were allowed to buy the computers that they wanted, we would sell even more. That's the point I make in my testimony.

There are two issues. One is the design specification problem, and the other is the issue of measuring life cycle cost, the true cost of a product to the Government. In a computer it's more than just the cost of the box, or the hardware. It's the cost of the hardware, and the software, but as we all know now, it's also the cost of maintenance and training. How long does it take you to become proficient on a range of programs, on a range of applications so that you can be really productive? We provide a technology that provides the Government with a major advantage there.

The question is, is the Government asking the question, how much does it really cost, for all of those issues? I maintain that it is not, and it needs to. We look forward to working with the Government in that regard.

Mr. Mineta. Mr. Chairman, if I might just ask one other question. As companies progress, or industries progress, we have also found many foreign companies coming in and buying U.S. companies. Should those foreign-owned U.S. companies be able to bid on U.S. Government contract?

Mr. Poulos. I believe the law prescribes that they must be allowed to.

Mr. Mineta. I don't know the reason, because I was just visited by a company—

Mr. Poulos. Unless there are certain security requirements that prohibit them, I think the law requires that they be allowed to bid.

Mr. Mineta. Northern Telecom, as an example in the communications business, is disallowed from bidding on U.S. companies because it is considered a Canadian company, but there are a number of others, in our own area, now we have Siemens buying Rolm. Should Rolm be able to market their PBXs with the Federal Government, as they are owned by Siemens? Should—oh, there are all kinds of examples.

Mr. Poulos. I think the U.S. Government would benefit from all technologies being available to the Federal marketplace just as our technology should have access to those foreign markets and to those foreign governments such as Japan, South Korea, India, Brazil, we'd like to see an open market with all players competing and being selected by the quality of their product.

Mr. MINETA. And in the absence of being able to get market entry, what should we do?

Mr. POULOS. Try harder.

Mr. MINETA. Thank you, Mr. Chairman, thank you very much.

Mr. HAYES. I'm going to recognize the gentleman from California, but first, to follow up, rather than take my home state, which in financial institutions is, as a result of both the crises in agriculture, and oil and gas, not a good example, I'll take yours in California.

Venture capital has vanished nationwide, not in the regions related to the circumstances of financial institutions. But, the observation that I think would be made by both those within the industry and close to it, and even in the securities industries, is that there are reasons for this which can be easily identified. One is return. A high risk venture capital has no greater return than is available on alternative markets with substantially less risk. Two, the institutions that are highly capitalized usually tend to be smaller. Even small business loans, as I would categorize Dr. Caulder's business, exceed loan limitations of those who have the highest capital structure, and therefore are more available to enter into a venture. And third, expertise. I don't think that we can sit here collectively across the country and name ten financial institutions that have anyone working for them in any department that is able to rate Dr. Caulder's loan, to determine whether or not that is an adequate risk for that institution.

We do not, as some governments are able to do, because of the interconnections of their commerce department (their equivalent of the Commerce Department), their equivalent of financial institutions, and the interrelationship of the equivalent of their large corporations, develop that inter-network of expertise, where when he walks in the front door of the bank nearest his home, or the sizeable institution in a large city nearest home, someone can make that financial judgment based upon what they're reading.

I think that one of the avenues we haven't explored today, and I've got to get the other questions, is that perhaps in addition to doing things where we're interested in creating a student product that is better than we do, we ought to also be talking about encouraging institutions for venture capital—but by the same thing, encouraging incentives of developing the expertise within the institution by which you can rate this kind of loan. And that's deplorably lacking, and there is no need. The institution itself will never expand in that area, because presently, there is absolutely no need to look for venture capital lending.

Thus, who do you inherit? You inherit someone not with the money, although that's essential, you inherit someone with the expertise to make the judgment as to whether that money has been properly invested and put to good use. That's the part that's so sorely lacking in our own financial structure.

I would be interested, at a later time, in your thoughts, from your relative experience, on how to improve that situation and how to perhaps encourage financial institutional services into developing departments of expertise that protect their dollars, and at the same time make capital available for good projects.

Let me jump first to the gentleman from California, and then I'll get back to the gentlewoman from Maryland who had one follow up question.

Mr. **Campbell**. I shall take but a moment. Thank you.

I wanted to address a question on international aspects of competitiveness, particularly, whether access to foreign markets is a critical component to get the efficiency size of scale of production in order to be competitive. If you could just take a moment and speak to the question, if I could put this question to Mr. Poulos and Dr. Caulder, in your businesses.

What sort of access problems have you had to foreign markets? If you could just take a minute and identify that, and do you agree with me that that's an important part of being competitive?

Dr. **Caulder**. Absolutely it's an important part. In anticipation of this, we knew the Japanese markets would be closed to us. One of the components of having a Japanese partner is access to those markets. That's why we have a joint venture there. That was the only avenue available to us.

In my past life, I managed Southeast Asia for a larger company called Monsanto. We tried to introduce a product in Japan over a long period of time, and we found that we could spend a lot of money for this product and get about a four or five percent market share. We could spend a little bit of money and get about a four or five percent market share.

After a few years, I wised up. Don't spend much money, you're going to get the same thing. So it was obvious, the market share was allocated to us. It continues to be allocated in many of the important areas. So for us to expand, we have to have access to those. Right now, we're using about the only means we have which is joint venturing with the people.

Mr. **Campbell**. Does Apple have the same problem?

Mr. **Poulos**. Apple sells its products in many countries around the world. Growth in those foreign markets is critical to our long-term success. Where we have frustrating bureaucratic barriers, such as in some of the Asian countries, we would encourage and applaud any action that the Government takes to help reduce those barriers.

Mr. **Campbell**. Would the Asian countries include Japan, Hong Kong, Taiwan, Korea and Singapore?

Mr. **Poulos**. Many of those.

Mr. **Campbell**. Would you care to delete any from that list—Hong Kong, Japan, Taiwan, Singapore, Korea?

Mr. **Poulos**. I wouldn't care to make that statement today, no.

Mr. **Campbell**. Treasury Regulation 1.861-8, the Foreign Source Allocation for R&D, this is an aspect that you may or may not wish to comment on. It's a rule of allocation of R&D to foreign source where the R&D in America can conceivably be tied to product sales, both here and abroad. Now we're kicking around the prospect of doing a 65 percent allocation rule.

I know this is not part of your testimony, but if it happens to be something on which you wish to comment, I'd be interested as to whether you think the 65 percent approach is satisfactory. If it's something on which you are not prepared to comment now, I would take that as well. Any of the members of the panel?

Dr. CAULDER. I'm not prepared on that, no.

Mr. POULOS. I'm not, no.

Mr. CAMPBELL. Thank you Mr. Chairman, those are all of my questions.

Mr. HAYES. Yes. The gentlelady from Maryland. I will ask since we do have another panel, although I've thoroughly enjoyed this, if we could keep that an equal opportunity on each panel.

Mrs. MORELLA. I will make it very brief. I was just wondering, because the R&D tax credit is going to cost something, $1.8 billion, how do we attempt to measure the effectiveness of it?

Dr. CAULDER. I think you're making a big mistake when you try to measure it. It goes back to basic research. If you try to measure it, you're always going to say, I'll take Apple as an example, had Jobs and his partners said, "Can we compete against IBM?" they would have closed that garage door in a hurry at that point in time.

You can't look at these things on a snapshot basis. You just have to say that the system has worked, when we have financed basic research, something good is eventually going to come out of it, I don't know exactly where it's going, but if you try to evaluate it through MBA Program 101 and put numbers to it, you're always going to kill it.

Mrs. MORELLA. Anyone else want to comment on that?

Mr. SWIHART. I might add something to that from general aerospace industry activity. Actually, our best competitive position is to build a better mousetrap and sell it before the other fellow does, and the success of that is because we would have had a negative trade deficit for several years, if it wasn't for the commercial aircraft sales to the United States companies.

I think the R&D credit is just one of those things that give us the capability of developing the technology at an early time and turning it into a better product.

Mrs. MORELLA. I would think there would be some signs in the future that we would see to indicate that to continue it permanently is helping. I'm talking about justifying it also with constituency. When you're putting almost $2 billion into this and then you talk about capital gains and you talk about these other things we need programs for, housing, and whatever—

Dr. CAULDER. I maintain that research dollars are opportunities, not cost. And when you refer to it as a cost of $1.8 billion, that mind set bothers me a little bit. It's an opportunity, not a cost, when we put money into basic research and into our educational system.

Mrs. MORELLA. Right. But it is a pragmatic dimension from this side. Thank you, Mr. Chairman.

Dr. CAULDER. I understand your problem.

Mr. HAYES. Thank you very much.

The next panel is Dr. Robert Lawrence, Dr. Robert Eisner, Mr. Stuart Eizenstat, and Dr. Allen Womack, Jr. The Chair will recognize the gentlewoman from Maryland. I believe she wishes to introduce a member of the panel. The rest of you, I suppose, will inherit me.

Mrs. **Morella**. I welcome the panel and I thank the Chairman for this particular courtesy. On the panel is a constituent of mine. He is somebody that we are all very proud of in this country, Mr. Stuart Eizenstat. He has held so many different positions that I couldn't possibly enumerate all of them, starting with domestic policy advisor on the Carter Administration, and he is appearing before us today, Mr. Chairman, as Counsel for the Council on Competitiveness and Research and Technology. I think he was on the "American Agenda" and is very involved in competitiveness and making our great country even greater.

So I thank you for the courtesy of allowing me to extend a particular welcome to somebody for whom I have great respect. I thank you.

Mr. **Eizenstat**. I appreciate that. I remember when Mrs. Morella knocked on my front door, looking for a vote.

Mrs. **Morella**. Now I leave for a Maryland delegation meeting.

Mr. **Hayes**. Thank you. We've got Stuart, who can't keep a job, let's see—

[Laughter.]

We also have Dr. E. Allen Womack, Jr., who is Vice President of Research and Development in Babcock & Wilcox, Dr. Robert Eisner, Professor of Economics at Northwestern University where I was once offered a scholarship, and for which I have had a great fondness ever since, even though I did not attend the University, and Dr. Robert Lawrence, a Senior Fellow in Economics at the Brookings Institution, where I was once invited to speak and was paid money for the engagement, so there is probably a huge ethics problem here, and we'll have to ask you to sit in the back and face the wall.

[Laughter]

Gentlemen, thank you. If you have a predetermined order, that would be fine, if not, then I suppose we'll begin in any other fashion. Had you predetermined an order of speaking? In that case, then I'll begin with Dr. Lawrence.

STATEMENT OF ROBERT LAWRENCE, SENIOR FELLOW IN ECONOMICS, BROOKINGS INSTITUTION, WASHINGTON, D.C.

Dr. **Lawrence**. Thank you very much, Mr. Chairman.

In the time that I have available, I'd like to ask five questions. I'm going to concentrate my remarks on the question of the R&D tax credit.

The first is, why should the Government be stimulating, be trying to have policies to stimulate commercial research and development? Let me put the stress on the commercial aspects and the development aspects of this process. Why not just give your money to basic research?

My answer relies on studies by eminent economists, in particular one by Edwin Mansfield at the University of Pennsylvania. He looked at the benefits to private firms from doing commercial R&D. He found that on average, they got a rate of return of about 15 percent. He then calculated: what returns had that commercial R&D

provided to our society as a whole? What he found was that the median return was 56 percent.

Others have replicated that study. Robert Nathan found a difference, again, of double the social rate of return, as double that of the private rate of return. Foster and Associates got four times the rate of return.

So the bottom line, in my view, is that the social returns to this activity are much greater than those that accrue simply to the firms themselves. The reason is simple. When you invent something, you cannot fully capture all the benefits of your invention.

Your competitors will emulate your invention. Competition will force you to pass on some of the prices that you would otherwise have, you will have to lower your prices.

So the variety of economic effects, which are well recognized, which argue that systematically, our society will under-invest in commercial R&D, and that's why the Government should be trying to do something to stimulate it.

The next issue is how should we stimulate it? I think there is no single avenue, but that the R&D tax credit is an appropriate mechanism for trying to stimulate this activity. Basically, it relies on the firms themselves to decide what's in their best interest, to let them spend the money to participate in the risks of the activities.

And, in fact, I would argue that if you are talking about a relatively small program compared to the total value of research and development spending, you're going to get more bang per buck with an R&D tax credit which effectively changes the incentives at the margin that those firms are considering, than you would, say, for a grants program.

The problem with a small grants program is that firms will send in their best projects. And of course, they will be in competition for the projects which they would undertake in any case.

The critical point about an R&D tax credit is that it can affect that margin. Well, has the R&D tax credit worked? My colleague, Martin Baily, and I have looked at this question, and we find that recent development spending during the period that the credit has been in effect, has been considerably greater than you would have expected.

We have also surveyed considerable evidence that indicates, as you might expect, that firms do respond to economic incentives, and that in fact, research and development spending does, if you lower the cost of research and development spending, firms will perform more of it.

We find, in fact—we looked across 12 different industries over the period 1981 to 1985, and we found in 11 of them that spending was higher than you would have expected given the fact, let me stress, that this was a period in which there was a very deep recession. Normally, you would have expected research and development spending to slow down during that period, and in fact, it held its pace and was much stronger than you would have expected.

We concluded that spending was about 7 percent higher than should have been expected. Now, and if you add the impact of the increase of spending to the fact that the social returns are much greater than the private returns, you get impacts on GNP that are considerably larger than simply the impact of the credit itself. In fact this is a case, given those high returns, where you can plausibly make the argument that eventually the stimulus to GNP will increase revenues to more than pay for that credit.

It is, in my judgment one of the few cases where the so-called Laffer curve actually operates, given the range of tax incentives that we have currently.

Nonetheless, there are some weakness with this R&D tax credit. In particular, because of budgetary restraints, it has been cut back. It used to be a 25 percent credit. It was lowered to a 20 percent credit. Ironically, the impact of tax reform made the benefits of any tax credit lower, and so that lowered the incentive effect.

In addition, more recently there was a partial disallowance of R&D expense, whereas originally the credit at the margin had an incentive which we would estimate as being around 7 percent, it's not the full 25 percent because when a firm qualifies for the credit in one year, it loses, by raising its base, it loses eligibility for the dollar of spending in future years.

Originally, we were talking about something like a 7 percent credit, today we're looking at something around 3.3 percent or under 4 percent. So what we've done is we've whittled away the incentive effect of this credit to the point where it is pure tokenism.

Now, I think that the new bill which has been proposed, H.R. 1416, makes a considerable improvement in the design of the credit. What it does is take the advice of the critics of the credit, who have pointed out that its incentive effect is much weaker at the margin than it could otherwise be and make it far more effective by changing the definition of the base.

And in fact, the way it is currently proposed, at the margin for firms qualifying for the primary credit of 20 percent, they will get a full 20 percent incentive at the margin for each dollar of spending. So we are making that credit for those firms five times as effective as the current 4 percent effective rate which they currently enjoy. This is being done overall, on the Treasury's estimates, without raising the overall cost of the credit.

In my judgment, the importance of research and development is such that I would like to see an increase in the overall commitment to the credit beyond that which is in the current budget.

Nonetheless, I would support the proposal to change the credit. Let me point out, even in the case of those firms who qualify for the 7 percent secondary credit, for them at the margin, the effect will be at least twice as great as it currently is today.

So we've got a mechanism by which we are going to get a far more effective credit with more stimulus to R&D, indeed one which could be around four times as effective for the same cost. I think that's a good deal.

Thank you.

[The prepared statement of Dr. Lawrence follows:]

Statement of Robert Z. Lawrence*
Senior Fellow, The Brookings Institution
before the
Subcommittee on Science, Research and Technology
of the
Committee on Science, Space and Technology
U.S. House of Representatives
May 18, 1989

The R&D Tax Credit: An Appraisal

The U.S. economy faces major challenges in the years ahead. There is welcome news that exports are rising and the trade deficit is coming down. But that deficit remains dauntingly large. We have a long way to go yet. There is welcome news that productivity growth in U.S. manufacturing is now running at over 3 percent a year. But in Japan, manufacturing productivity growth last year was higher than ours, and the European economies are on the move again. If the United States is to retain its position as the most productive economy, we must maintain or even improve our performance. We can hope that the worst of the economic problems of the past 15 years are behind us, but the challenges of the future will be tough.

Improving the economy will take efforts in many directions. The workforce needs more skills, education and motivation to add to its contribution. Investment in new plant and equipment should increase if we are to equip the workforce appropriately to compete. And the United States must continue to develop the innovative products and processes that have been its competitive strength and its major source of productivity growth. The federal government has traditionally played an important role in sponsoring technology development and today the National Science Foundation, the Defense Department and other agencies direct resources into basicscience and technology. And of course since 1981 the R&D tax credit has been an important part of the federal commitment to innovation.

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*This statement was prepared jointly with Martin Neil Baily, Senior Fellow, the Brookings Institution. The views expressed do not represent those of the Brookings Institution, its officers, trustees, or other staff members. This statement draws on analysis commissioned by the Council on Research and Technology.

It is now widely recognized that commercial R&D is vital to U.S. competitiveness and growth, and that an R&D tax credit can help to overcome the "appropriability problem" with R&D spending. When a company spends its own R&D dollars to develop a new product or process, the benefits spill over outside the company in ways for which the company itself will not receive payment. Competitors will copy the new technology. Research and engineering staff will leave to join other companies or set up their own, taking their knowledge with them. For these reasons the innovating company cannot "appropriate" all of the returns to its own R&D. Some of the benefits accruing to its competitors, its customers and its employees will not be paid for. As a result, firms will spend less on R&D than would be desirable from the perspective of society as a whole, unless there are additional incentives from the government.

Some economists acknowledge the case for government intervention but object to the R&D credit on the grounds that government support should be concentrated only on basic research. There is a need to support basic research, but the evidence suggests that, in the United States, firms do not engage in sufficient commercial R&D spending. Although they use different methodologies and data samples, most studies have reached the same conclusion: Industrial R&D has social returns that far exceed the returns from other kinds of investment.[1]

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[1] Three complementary studies commissioned by the National Science Foundation support this conclusion. Professor Edwin Mansfield and his

These studies point clearly to the need for increased incentives for private companies to do more R&D. An R&D tax credit increases the efficiency of the market system, rather than distorting it, something that is true of very few other special provisions of the tax code. The strength of the case for an R&D credit has been recognized by the Senate, the House, and the administration, even in the face of the budget deficit problem.

Other economists argue that the government or a committee of experts should be given the task of picking the commercial projects with the highest social payoff. And some even go further and suggest that particular kinds of firms, e.g., high-tech, smokestack, large or small, should be favored. In some cases, e.g., superconductivity, support for a particular technology project may be warranted. But for the most part, we are uncertain where the highest social returns will be realized, so it is better to give a general incentive that is available to all firms. This is the essential philosophy behind the R&D credit: while the government provides additional leveraging, a broad spectrum of firms decides which projects should be supported.

The use of a tax credit exploits the strength of the private market. Commercial R&D involves finding innovations that will succeed in the market, not just those that are feasible technically. Successful innovation

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associates at the University of Pennsylvania analyzed detailed data on a sample of seventeen typical innovations. They found that the median project in their sample had a rate of return to the firm undertaking it of 15 percent. However, once they took into account the benefits accruing to other firms and consumers, the median return to society was 56 percent. In a similar study, Robert R. Nathan Associates found the median social rate of return to be 70 percent, about twice the median private rate of return. And Foster Associates found the median innovation had a social rate of return of 99 percent and a private rate of return of 24 percent.

requires knowledge of market conditions and the needs of customers. The tax credit channels federal support to the people who are best able to choose commercially worthwhile projects and bring them to fruition. We support federal funding of basic science. But such support is no substitute for the R&D credit.

In fact, tax incentives are likely to be more effective in stimulating R&D spending than a grants competition with a similar budgetary cost. When government grants for R&D are made available, private companies will respond by seeking funding for their best projects, i.e., those they would undertake anyway. An R&D tax credit, by contrast, can affect decisions at the margin.

The Strengths of the Existing Credit

- The credit that was in effect from 1981-85 increased private R&D spending. In an earlier study we examined the evidence on the effectiveness of the credit and then carried out their own investigation of the data.[2] We reviewed several independent studies that concluded that the credit has succeeded in raising spending, although they found that the impact was not very large. Our own analysis used more up-to-date information than in the other studies and it confirmed that the credit had raised spending. Moreover, our analysis indicated that the credit was more effective than had been thought. The ratio of R&D spending to output during the period when the credit was in effect grew more than twice as rapidly as in the comparable period prior to the enactment of the credit. In a statistical analysis, we found that the credit increased R&D spending in 11 out of the 12 industries studied and raised overall R&D spending by $2.6 billion a year.[3] These results proved robust when we asked if there were alternative explanations of the increased R&D spending over the period.

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[2] Martin Neil Baily and Robert Z. Lawrence, Tax Policies for Innovation and Competitive, study commissioned by the Council on Research and Technology.

- The social return to R&D is so high, that the credit is worthwhile even if its impact is small. Many people judge the credit on whether it can encourage more R&D spending than its costs in tax revenues. And the findings we have just described suggest that the 1981-85 credit passed that test. But in fact this is not the correct test. Because the social rate of return to R&D is twice or even four times the return to the private company performing it, this means that it is worthwhile for taxpayers to encourage R&D even if more pessimistic estimates of the credit's effectiveness turn out to be correct. The credit will raise GNP and pay for itself in the long run even with a very conservative view of its impact.

Problems with the Existing Credit

- The credit provides only a small incentive, and its effectiveness is being eroded by revisions of the code. The credit that went into effect in 1981 had a statutory rate of 25 percent on spending above a base level. But the incentive effect was much less than 25 percent, because of the way the base was computed. In particular, current spending increases the future base and thus limits the incremental incentive. We calculate that, on an after-tax basis, the original credit reduced the after-tax cost of a proposed new R&D project by only 7 percent. In addition, as Robert Eisner has pointed out, the credit could even act as a disincentive to R&D for a company that was cutting back its R&D spending below its base.

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[3] These results refer to the period 1982-85. The credit was only in effect for part of 1981.

The credit was renewed for three years effective in 1986 at a lower statutory rate and its incentive effect was reduced further because of (1) the reduction in the corporate income tax rate and (2) the enactment, last year, of a provision which offset the benefits of the credit with a disallowance in the expensing of R&D spending. The credit today provides an incentive to R&D spending for qualifying firms which is less than 4 percent. An incentive of this magnitude is simply tokenism. It acknowledges the social need to stimulate industrial R&D but does virtually nothing to achieve it. The R&D tax credit cannot be effective unless it provides an adequate incentive.

- A temporary credit has only a limited impact. Some R&D directors report that the credit has only a minor impact on their R&D budgeting decisions. And no wonder. Not only is the incentive effect small, but companies do not know whether or not the credit will even exist in the future. An R&D project planned today will often involve spending over many years into the future. Indeed it is long-term planning that we wish to encourage in our companies. A credit that will disappear in a couple of years will not provide the stable incentive needed for long-term R&D planning.

- Many companies now miss out on the credit altogether. When the credit was enacted it applied only on spending in excess of the base level. At a time when the majority of companies were raising spending, this was seen as a reasonable tradeoff between the goals of giving an adequate incentive and minimizing revenue loss. The credit's structure is no longer appropriate for the times. Many U.S. companies have raised their R&D to sales ratios but since their sales levels have fallen or failed to grow rapidly, they cannot maintain the increases in R&D that were achieved in the past.

The scope of the credit should be as broad as possible. Encouraging declining firms to undertake more R&D could be as beneficial socially as encouraging those that are expanding to spend more. The existing credit provides no incentives for companies who have fallen behind in R&D spending to catch up, and provides little incentive for companies that have achieved high levels of R&D spending to hold that level.

The Proposed Restructuring of the Credit

Recently there have been proposals to restructure the credit and make it permanent. In particular, representatives Jenkins, Frenzel and Pickle have have proposed that the R&D tax credit be extended in a revised form. The Administration has also indicated its support for an extension of the credit, proposing a basically similar form to H.R. 1416, the Jenkins-Frenzel-Pickle proposal.

The existing tax credit has been a valuable tool to encourage growth. A revised and permanent credit would be much better. The improved design in these proposals would significantly enhance the efficiency of the credit by dramatically raising incentives and increasing coverage.

The new credit would be in two parts. The Treasury has estimated that a revision which did not raise the revenue loss to the Treasury could be achieved with primary and secondary rates of 20 and 7 percent respectively.

The primary credit would be 20 percent on R&D spending in excess of a base level. The base level in 1990 would be a percent of the average spending in earlier years. In subsequent years the base would rise in line with the increase in GNP. The secondary credit would be 7 percent on spending in excess of 75 percent of the base level. Companies would be free to choose either credit in each year.

The typical company which has matched the growth rate in overall US R&D spending over the past decade would be eligible for the primary credit. Since its additional spending in 1990 would not affect its base in future years, with the new credit, the cost of its marginal R&D project would not be reduced on an after-tax basis by the full credit. This would result in an after-tax incentive of the full 20 percent 5 times as large as the old credit. The new credit would provide a substantial incentive to add extra projects. While the incremental impact of the credit would be significant, the subsidy to R&D would remain a relatively small proportion of total R&D spending. A representative company would receive a credit equal to only about 3.5 percent of its 1990 R&D spending. This representative company would be given an important incentive at a relatively small cost to the Treasury.

What about companies whose R&D spending grows more slowly? A company whose R&D had grown by 3 percent a year after 1983 would select the secondary credit. This would provide an incentive which is about twice as large as that received by eligible companies under the old credit formula. Moreover, under the old credit formula many such companies would not be eligible for the credit and some might have found themselves with an incentive to reduce R&D spending. However, no such disincentives occur with the new formula.

As with the primary credit, the improved incentives for additional projects is achieved at relatively small overall costs. A company eligible for the secondary credit but just below the threshold for the primary credit, would receive a subsidy equal to only 2.4 percent of its 1990 R&D spending.

With both the primary and secondary credits, over time, companies will have their bases rise automatically. In future years, they will have to increase spending as fast or faster than GNP in order to avoid a gradual reduction of their credit.

The Advantages of the Proposed Credit

- For companies whose R&D is growing strongly, the proposed credit provides an incentive for additional R&D five times as large as the current credit. It does this with no further loss of tax revenue. By combining a high credit rate for any additional project with a low average rate overall it does exactly what it should: It rewards companies that add to their R&D spending and, for the most part, avoids rewarding them for R&D that was being done anyway.

- The proposed credit broadens the range of companies eligible for the credit and encourages those that have had hard times to resume the growth of their R&D spending. It provides a solid incentive to these companies, but again, the average credit rate is low. The 7 percent incentive in the secondary credit is still twice as high as the incentive in the current credit.

We have calculated that the proposed new credit would provide companies with about 3 to 5 times as large an incentive for greater R&D spending as the credits in effect in the 1980s. At the same time, the Treasury has estimated that the new credit we have considered would cost the same tax revenue as the credit currently in effect. In terms of effectiveness per dollar of revenue loss, the proposed credit is better by a factor of 4 to 1.

There have been different estimates made of the increase in R&D spending induced by the credit in effect between 1981 and 1985. These have ranged from $500 million up to $2 billion in extra R&D. Based upon the same underlying assumptions about the responsiveness of companies, the proposed new credit would raise spending by between $1.3 and $5.2 billion. Since the revenue loss of the credit is thought to be about $1 billion, the new credit is clearly an excellent policy, even under the most conservative assumptions about how businesses respond to tax incentives.

To many people it seems paradoxical that the new credit could have a much bigger impact on spending without having a much bigger revenue loss. The basic reason is that the new credit uses a base indexed to GNP growth. A company that raises its R&D to sales ratio is not raising its future base or cutting its future credit, as is the case with the old R&D credit. Under the proposed new credit, companies that fall behind GNP growth will receive less credit (keeping the revenue loss down), but companies that step up spending will get more benefit (the incentive effect).

Conclusions

The proposed credit represents a substantial improvement over the existing credit. The U.S. economy today is in a rather different phase than the one it was in 1980-81. R&D spending has grown rapidly since then and now the main task is to hold the new higher level to achieve this. It avoids the adverse incentives built into the existing credit by adjusting the base with GNP rather than in response to each company's own spending.

We urge the passage of a revised Credit. Ellen Rosenthal, a reporter for Tax Notes, talked to many people including critics of the existing credit about this proposal and she writes: "No one interviewed for this article opposed the proposal." We also urge the Congress to resist efforts either to cut the effective credit rates or make the extension of the credit temporary.

Mr. HAYES. Thank you.

Probably it would be best to follow an economist with an economist, so, Dr. Eisner, if you please.

STATEMENT OF ROBERT EISNER, PROFESSOR OF ECONOMICS, NORTHWESTERN UNIVERSITY, EVANSTON, ILLINOIS

Dr. EISNER. Thank you very much, Mr. Chairman. I welcome the opportunity to be here. If you hear more than one economist, you will certainly hear more than one opinion, I know you expect that.

Dr. Lawrence did refer to critics of the R&D credit. He mentioned Professor Mansfield. Let me mention that I was one of those commissioned by the National Science Foundation some five or six years ago to do a study of the R&D tax credit to see how it was working. They are of course, not responsible for my findings.

I did find that it was something of a monstrosity. I think the current proposal is a substantial improvement, in part, I do believe, as Dr. Lawrence has suggested, because of our criticisms, particularly in regard to the base. It will make it less perverse and perhaps more effective.

Dr. Lawrence did not point out that Professor Mansfield, among other things, had also done a study in which he found that tax credits here and in a number of European countries were quite ineffective, had a very low bang for the buck and had not been successful in stimulating much R&D spending.

My own work very strongly confirms that. I can point to a table in which just even on a very crude basis you note that the R&D expenditures in real terms in the six years before the credit was instituted, grew at about a 6.2 percent annual rate, and in the six years since they grew at a 3.8 percent rate.

Now, there are a number of defects remaining in the current R&D credit. While I am going to end by suggesting there are much better ways to support science and technology and to support research, and I do think there is a major role for Government support in research alone, in a number of the ways that have been proposed already this morning.

But if you were to go with this credit, you've got to recognize that the important thing of the credit, despite I might say, not disrespectfully, a lot of special pleading. The important thing is not to make companies richer. In a way, ideally, you hope not to give them a penny more. You simply want to goad them, give them an incentive to do something they would not otherwise do.

In the way the credit is still structured in the current proposals of the bill before the Congress, there are a number of difficulties. One of them, for example, is this 50 percent base requirement. What that means is that, for companies that would be increasing their R&D most rapidly, the incentive is substantially reduced and indeed they're given some incentive to delay their expenditures until some time when they are not caught in that increase.

A second problem remaining is that companies that don't have any tax liabilities, they may be quite numerous perhaps despite the new tax reform, may at best give some deferral of taxes out of this, but they may not even get anything. And there are of course still the firms who go completely below base; and there are new firms which are not going to have tax liabilities, the ones you're most concerned with, many of them don't have profits on which they're paying taxes.

There is further in the new proposal, I have to say, and I think guided, I'm afraid, unfortunately, by the feeling that perhaps politically that everybody had a share, the 7 percent thing which is another very perverse factor. Having an alternative base means that you're going to have a situation where firms who would otherwise spend a little bit more than base and entitle themselves to the 20 percent credit, will calculate—you can perhaps see from my paper and work it through sometime—will calculate, unless they're going to go to 13.5 percent over base, they would do better to actually use a 7 percent credit. Using the 7 percent credit as Dr. Lawrence or others would acknowledge, simply obviously reduces the incentive effect to them by about two-thirds.

But those are defects in the proposed bill. I will acknowledge, and I think thanks to our criticisms, it is certainly better than the existing law. I am puzzled that anybody should ever have expected there to be any benefit from the existing law, because it's been well documented that the nature of it, because of the company-specific adjustable base, was such that all the firms could possibly get out of it, if they were rational, was a postponement of tax liabilities, and not an elimination of them.

Therefore, they would at best get some saving, in terms of the value of having their money earlier rather than later, and in a number of cases, as I have suggested, it was perverse, because of the fact that they were below base, or could be below base, and the like.

But other than that, lets then come finally to, I think the most basic question this Committee has to face. I really appeal to this Committee perhaps as much or more than to the Ways and Means Committee. You are concerned with a broad problem of supporting science, and supporting research.

As Dr. Lawrence pointed out, as any economist indicates, the critical question is, is there any reason for Government to tell a business to do what it is not otherwise going to do? Why should it give it a tax advantage? Why should it give it an incentive? Why should it lose the taxpayers money?

I think we have to remember there are opportunity costs. Is there something else you can do with a billion or a billion and a half dollars that the Treasury will be losing? I would say there is a lot that can be done with it, and along the lines of providing what private firms cannot provide. That is a basic pool of qualified scientists and engineers that they can use in R&D, that will give them the basis for finding R&D profitable, and using it for themselves.

The problem with the current proposals is that they apply to all R&D spending. The National Science Foundation will give you figures pointing out that only 3.8 percent of R&D spending, company-funded R&D spending, is basic research. It's that basic research that is not likely to have an immediate payoff to a company. The payoff to that basic research will be to the entire economy. So that's particularly the kind of thing the Government should be supporting.

However, 22.5 percent of a company-funded R&D is applied research, and 73.7 percent is development. The bulk of that I would insist, is spending which may well be very useful, but there is no reason to use the tax code to tell a company, "we know better than you, you should be spending more on this R&D research than you find it profitable to spend."

That is not the argument for supporting education, for supporting the funds for graduate students in science and engineering. I think what this Committee has to worry about are the reports, which I'm sure you must all have heard, about 13-year olds, who are given tests in science and math, and compared with the Japanese, South Koreans, Europeans, and Canadians, and we come out dead last.

There is nothing there that Apple Computer or—well, maybe Apple Computer can do something, you know, in sending computers around—but that is something that really needs Government support, support for education, support for graduate study, and science and engineering, perhaps graduate studies generally.

To fiddle with an R&D credit to lose more money on that, given the perceived budget stringencies I think is the wrong way to go.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Eisner follows:]

Tax Credits and Other Measures to Support Research and Technology

Prepared Statement of Robert Eisner

for

U. S. House of Representatives

Committee on Science, Space and Technology

Subcommittee on Science, Research and Technology

May 18, 1989

Hearing on

Federal Government's Role in Stimulating Private Sector Investments in Research and Development Activities

Tax Credits and Other Measures to Support Research and Technology

Robert Eisner[*]

A few years ago I characterized the R&D tax credit then scheduled to expire at the end of 1985 as a monstrosity costing the U.S. Treasury some $1.5 billion per year with no clear payoff. Current proposals for a new credit beginning in 1990 offer major improvement over previous versions. Serious doubts remain that any such credit is wise public policy.

The existing credit, as pointed out originally by Eisner, Albert and Sullivan ("The New Incremental Tax Credit for R&D: Incentive or Disincentive?", National Tax Journal, June 1984) had a number of perverse features. The most serious of these, a base which moves on the basis of the company's own expenditures, is eliminated in current proposals. The new versions of the base, however, are defective in a number of respects and other deficiencies remain.

By tying movements of the base to an aggregative indicator not significantly affected by the firm's own R&D expenditures, current proposals avoid the future penalty which largely vitiates any incentives to increase R&D and in some cases actually makes it desirable to reduce R&D spending. The nominal 20 percent credit for those companies who take advantage of it under current proposals would, except for the disallowance of deductions, be an effective 20 percent, compared to some 3¼ percent under existing law.

Offering an alternative 7 percent credit over a 75 percent base, apparently in the interest of spreading the tax benefits to a larger group of firms, to a considerable extent, though, wipes out this added incentive. Rational firms should calculate that unless their expenditures are and can be expected to be at least 13 percent over base, they will do better to opt for the 7 percent credit. Such firms would enjoy tax savings with very little incentive to increase their R&D expenditures.

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[*] William R. Kenan Professor of Economics, Northwestern University, and past President of the American Economic Association.

The Office of Tax Analysis estimates that only 55 percent of expenditures would prove subject to the 20 percent credit, 25 percent would fall in the 7 percent category and 20 percent prove subject to no credit. It would appear probable that the desire to minimize uncertainty as to the benefits would in fact increase the 7 percent group at the expense of the 20 percenters.

Incentives are further lost for firms subject to the 50 percent base limitation. These firms in effect receive only a 10 percent credit on increases in expenditures beyond the point where the limitation applies. They would indeed do well to reduce their planned R&D spending, delaying increases until periods in which they will not fall afoul of the limitation.

Use of a credit rather than an outright subsidy also means that there is no incentive at all, except for carry-forward provisions where they prove relevant, for firms without tax liabilities. This may apply particularly to innovative new firms where help would be most significant. And while the 1986 tax reform should have reduced this category, there may well remain substantial firms with so much in the way of other tax advantages that they have little or no tax liabilities against which to offset the credit. Finally firms below 75 percent of base, that do not foresee the possibility of rising above that point, have no incentive to increase R&D spending or even to maintain their current rates.

An optimal credit or subsidy from the point of view of increasing R&D spending is one that maximizes the bang for the buck, one that minimizes Treasury loss of tax revenue while offering the greatest incentive to firms to alter their behavior. The object is not to make recipient firms richer at the public expense but to make them do something they would not do otherwise. Ideally, for each firm the "base" would then be just the expenditures it would have undertaken without any credit.

In moving the base with the firm's own expenditures, current law aims at that ideal but, as is now widely understood, incentives are vitiated by the recognition that with this provision current credits reduce future credits. Moving the base on the basis of an aggregative measure removes that difficulty at the cost of divergence of the base over time from the ideal that would avoid giving firms credits for expenditures they would have undertaken anyway, without the tax benefits. The GNP growth measure for adjusting company bases, in current proposals, can be improved upon.

I have suggested previously, and would urge again, that the adjustment be made on the basis of actual R&D expenditure of some aggregate large enough so that it would not be affected in any major way by the firm's own expenditures. This then might be the total of company-funded R&D expenditures as reported to the National Science Foundation or the expenditures reported to the Treasury. (There is some difficulty with the latter since firms not claiming the credit are not currently required to report.) Better still, each firm might be asked to indicate the industry, more or less narrowly defined, to which the bulk of its R&D expenditures apply. Its base would then be adjusted annually in accordance with the previous growth of R&D spending in that industry. By making use of tax-payer reporting, with the usual penalties for dishonesty, added administrative burdens would be avoided.

The question remains, even with the best of incentive schemes, how much R&D spending will actually be increased. Sober analysis of experience of other countries as well as our own is not encouraging. As I pointed out in the article in Issues in Science and Technology attached as an appendix to this statement, in other professional articles and in testimony to the Ways and Means Committee, the weight of the evidence is that R&D expenditures increased substantially less than the revenue lost by the Government.

Indeed, experience with our own Research and Experimentation Credit has by simple measure been most discouraging. As shown in Table 1, real R&D spending grew at a 6.2 annual percent rate from 1975 to 1981, before the institution of the credit, and at only a 3.8 percent rate from 1981 to 1987 with the credit in effect. There may well have been other factors at work counteracting the gains that some claim for the credit, but I have failed in more sophisticated analysis to find such gains. And of course, as pointed out, the current credit has been a particularly poor one. But with this record the burden of proof must surely be on those who would claim that any credit would do much good in actually raising R&D spending.

The central question, however, is whether any tax credit is warranted. A basic general principle, which should not be violated without very good reason, is that competitive business should be allowed to do what seems most profitable, with its decisions undistorted by government regulations or tax considerations. Put simply, a free market has great advantages. The tax code then should not be cluttered with special provisions designed to induce firms to do for tax benefits what they do not see fit to do in the interest of their own productivity, efficiency and profits.

The argument that R&D spending is properly an exception to the principles of free markets and tax neutrality is that it has much of the quality of a public good. Since new discoveries and resultant technological advances by one firm have benefits for others and the economy as a whole, the lure of merely its own profits will not generate an optimal amount of investment in R&D.

The main problem with that argument, in the current instance, is that it would appear to apply to basic research, considerably less to applied research and hardly at all to development of knowledge already in the public domain. But of the $55.5 billion of company-funded R&D reported by the NSF in 1987, only $2.1 billion or 3.8 percent was for basic research. Applied research comprised $12.5 billion or 22.5 percent and development came to $40.9 billion or 73.7 percent of the total. The University Basic Research Credit does little to alter this, as the 1987 figure for university research using industrial funds was only $481 million. It would appear then that the great bulk of the tax credits have been going to firms for expenditures the benefits of which redound overwhelmingly to themselves. They would have every reason to undertaken them to an optimal amount without extra tax inducements. To the extent tax incentives were effective in this case they would in fact be leading firms to spend more than optimal amounts on R&D, thus leading them to reduce their expenditures below optimal amounts on other forms of investment, such as in plant and equipment or in the human capital of a highly skilled labor force and management.

I share the concern of many that lack of progress in science and technology represents a serious threat to our future well-being. I also believe that investment to achieve such progress does very largely have the quality of a public good warranting public support. The direction of that support, though, should be in basic research and in basic education and training.

Our problems are manifested early when American 13-year-olds rank last in math and science scores on standardized tests taken by students in a number of countries of Europe, Asia and North America. They show up again in the extent to which our College and University students spend time on subjects students in other countries have learned in secondary schools. And they show up in declining rates of growth, particularly in the physical sciences and engineering, of the numbers of graduate students in doctoral-granting institutions.

The one billion dollars or so of annual lost tax revenues envisaged in current R&D credit proposals -- an amount that would grow over time -- may not seem inordinately large in an era of trillion dollar budgets. I can think of many places, though, in which that billion could go much further in promoting science, research and technology.

Take the matter of support for graduate training for example. In 1987 there were 283,200 full-time science and engineering graduate students, some 202,000 excluding psychology and the social sciences, and 117,146 in engineering and physical, environmental, mathematical and computer sciences, alone. One billion dollars could fund 100,000 graduate students with annual fellowships of $10,000 each. What might be the improvement in quantity and quality of scientists and engineers from such funding?

If we are looking for incentives, what about the use of a billion dollars to induce elementary and secondary schools to improve the quality of their teachers and teaching in math and science? Or what about increased direct

Government spending for basic research or subsidization of Universities or other non-profit institutions in that research?

One may conjecture that public spending of this kind would in the long run do more to increase R&D expenditures, and increase them in a productive manner, than any of the proposed R&E tax credits. A highly skilled force of available scientists and engineers and solid foundations of basic research might make R&D look much more productive and profitable to firms. They would then undertake that spending on their own on the sound motivation of market forces rather than at the behest of the IRS.

Table 1: Company-Funded Industrial R & D Expenditures, 1975-88*

(1)	(2)	(3)	(4)	(5)	(6)
	Millions of		Average Annual Percent Rates of Growth		
Year	Current Dollars	Constant 1982 Dollars[1]	Years	Current Dollars	1982 Dollars
1975	15,582	26,272	1975-77	11.4%	4.6%
1976	17,436	27,645	1977-80	16.4%	7.3%
1977	19,340	28,746	1980-83	12.0%	5.1%
1978	22,115	30,672	1983-86	7.2%	4.0%
1979	25,708	32,720	1983-87	6.7%	3.4%
1980	30,476	35,553	1975-80	14.4%	6.2%
			1980-87	8.9%	4.1%
1981	35,428	37,705			
1982	39,512	39,512	1975-81	14.7%	6.2%
1983	42,861	41,268	1981-87	7.8%	3.8%
1984	48,308	44,842			
1985	51,439	46,362	1981-88	7.6%	3.7%
1986	52,848	46,386			
1987	55,500	47,166			
1988, Projected	59,100	48,550			

*Source: National Science Foundation, National Patterns of R & D Resources, 1989.

[1] GNP implicit price deflators used to convert current dollars to 1982 dollars.

Tax Credits and Other Measures to Support Research and Technology

Prepared Statement of Robert Eisner

Appendix. "The R&D Tax Credit: A Flawed Tool"

From Issues in Science and Technology.

Volume 1, Number 4, 1985.

THE R&D TAX CREDIT: A Flawed Tool

Robert Eisner

PROLOGUE: *Finding irrefutable evidence that the R&D tax credit is an effective device to stimulate corporate spending on R&D has proved difficult. Total corporate R&D expenditures have increased since the credit was enacted, but they were rising at an even faster rate before the credit became available. Other incentives to raise R&D spending are also at work, and it is not easy to gather valid data on what motivates corporate managers.*

Critics say that the credit works unevenly, benefiting only those companies that pay corporate taxes and offering little incentive to start-up firms or older smokestack industries, even though the credit can be carried forward for up to 15 years to reduce the tax bite on future profits.

Here, economist Robert Eisner examines the evidence and finds the R&D tax credit seriously flawed. On purely analytical grounds, he argues, the current credit will have limited positive effects and may in some instances even have perverse effects. But even if the defects in the current law were corrected, Eisner says, it is questionable whether government efforts to promote R&D spending by private firms are appropriate in a competitive, free-market system.

Robert Eisner received his B.S.S. degree from City College of New York in 1940, his M.A. from Columbia University in 1942, and his Ph.D. from Johns Hopkins in 1951. A fellow of the American Academy of Arts and Sciences and of the Econometric Society, he is the William R. Kenan Professor of Economics at Northwestern University. He is the author of Factors in Business Investment *(1978) and has written extensively on issues of monetary and fiscal policy, unemployment, and economic growth.*

The road to hell, it is said, is paved with good intentions. I am not about to argue that the R&D tax credit, euphemistically labeled "R&E" for "research and experimentation," will in itself lead the nation to doom. But it has proved to be a misguided step in an uncertain direction.

The argument for government support of R&D in a free enterprise economy is simple. To the extent that benefits of research flow outside of firms undertaking it, each individual company is likely to underinvest, undertaking only those expenditures for which its own likely benefits exceed its costs. But accepting the principle—as I do—that government policy should encourage more research does not answer the question of how that should be done. The current tax credit for research and development, scheduled to expire at the end of 1985, has proved something of a monstrosity, costing the U.S. Treasury some $1.5 billion per year with no clear payoff. It has been an expensive experiment.

The current tax credit for research and development has proved something of a monstrosity.

II

Under the current law businesses are offered a tax incentive to increase R&D. Specifically, they are allowed a credit against tax liabilities equal to 25 percent of the excess of qualified R&D expenditures over their "base," now defined as the greater of (1) the average of their expenditures over the three previous years, or (2) half of current expenditures. If the firm cannot currently use the tax credit because it has insufficient tax liabilities, or none at all, it can carry unused credits back 3 years and forward 15 years.

On purely analytical grounds the potential of the current credit can be shown to be substantially limited. First, it clearly offers no tax benefit and no incentive to firms whose R&D is below the base established by previous R&D expenditures. In fact, such firms will rationally *reduce* their current R&D spending in the expectation that by lowering their future base they will enjoy a tax benefit later.

Second, those firms that were *already* planning to increase R&D spending by more than 100 percent of their base will actually enjoy a credit on any additional R&D spending of only 12.5 percent rather than the nominal 25 percent. For such firms the base will be 50 percent of current expenditures, and each additional dollar of R&D spending, because it increases the base by 50 cents, will increase the excess over base by only 50 cents. The credit of 25 percent, applied to this 50 cent excess, will thus amount to only 12.5 cents.

For these firms too, then, the presumed tax incentive for R&D is actually perverse. They would be better off reducing their spending to a level that constitutes no more than a 100 percent increase over the average of their previous spending. They would be losing only 12.5 cents per dollar of reduced R&D spending in terms of current taxes, but could expect to gain 25 cents in future tax benefits by lowering their base.

Third, many firms, especially in the rapidly growing high-tech field, have no tax liabilities against which to apply the credit. Unless they have had such liabilities over the past three years, which is particularly unlikely for new firms, they gain nothing from the carryback provision. And since, as we shall see, the benefit of the tax credit is in the present value of postponing taxes, they are likely to perceive little gain from the carryforward provision, and no gain at all if tax liabilities are not anticipated over the next three years.

A fourth and overwhelming problem with the current credit is the calculation of a base that adjusts with the firm's own previous expenditures. This vastly reduces the incentive effects of the credit, and this defect would become critical if the credit were made permanent. Firms would then reckon that any increase in current R&D expenditures would raise the base to be subtracted in calculating the credit for future expenditures. Firms with generally increasing R&D expenditures (whether real increases or increases due to inflation) would not obtain the benefit of a reduction in taxes but only the benefit of postponing them over a three-year period.

For example, a $12 increase in R&D spending would reduce taxes by $3 in the current year, but it would raise the base by $4 and raise taxes by $1 in each of the succeeding three years. Except for the fact that time is money, and it is better to pay taxes later than to pay them now, the firm would have no benefit at all.

Since time *is* money, we should indeed calculate the difference between the $3 current tax saving and the present value of the increased tax of $1 in each of the next three years. At a 10 percent rate of discount (reasonable with current interest rates), that present value becomes $2.49, thereby wiping out all but 51 cents of the original $3 gain. Thus, the nominal tax credit of 25 percent translates into a gain of 51 cents on $12 in R&D expenditures, or an effective tax credit of only 4.3 percent.

Paradoxically, firms would have a much greater incentive to increase R&D if they did not expect the credit to last. If Congress were to make it clear that the current credit would not be extended beyond 1985, the effective credit would be the full 25 percent, because increasing current expenditures would bring no offset of a reduced credit and higher taxes in the future.

An analysis of special tabulations of 1981 tax returns prepared for me by the Office of Tax Analysis of the Treasury, as well as other data, indicate that there is real substance to these analytical perversities.

First, as against a "tentative credit" of $872 million (for the half year of 1981 that the credit was in effect), the credit actually claimed was only $630 million, indicating a shortfall of 28 percent due to lack of current tax liabilities. Of $13.4 billion of reported qualified R&D expenditures, as shown in Table 1, only $9.2 billion, or 68.6 percent, were incurred by firms with sufficient tax liabilities to claim all of their potential 1981 credit.

Second, the proportion of qualified R&D by firms that reported R&D up by more than 100 percent, so that their nominal marginal credit was cut in half, came to 9.2 percent. Of the $9.2 billion of R&D on which a credit was claimed, $0.7 billion was spent by firms with R&D spending increases of more than 100 percent. Thus, only 63.2 percent of total qualified R&D expenditures ($8.5 billion out of $13.4 billion) were incurred by firms with tax liabilities against which they could claim the full credit. And this does not take into account some 6 percent of expenditures by firms who would not have sought the credit because their 1981 expenditures were below their base.

Another count against the current R&D tax credit is that it is procyclical.

R&D expenditures, like all other expenditures, tend to slacken during recessions. Since the credit is tied to the rate of growth of R&D expenditures, it is particularly sensitive to such slackening. A decline in rate of growth from, say, 12 percent to 6 percent would cut the credit in half. Further, since more firms suffer losses in a recession, tax liabilities against which the credit can be claimed are reduced. Our examination of Standard and Poor's Compustat data revealed that in the recession year of 1982 the proportion of R&D expenditures undertaken by firms with tax liabilities and expenditures above base was down to 52.7 percent. On both counts, therefore, the R&D tax credit tends to be lower in a recession, when tax reductions would appear particularly desirable to stimulate the economy, and higher in booms, when a tighter tax policy might appear useful to prevent inflationary excesses. Indeed, since the credit relates to increases in nominal R&D expenditures, inflation serves to increase the credit and reduce taxes, again the opposite of what would be indicated by appropriate countercyclical policy.

TABLE 1:
R&D EXPENDITURES, 1977-80 (PRE-CREDIT) AND 1981-84 (CREDIT)

YEAR	COMPANY FUNDS FOR R&D		RATES OF GROWTH	
	Current Dollars	1972 Dollars	Current Dollars	1972 Dollars
	(Millions)		(Percent)	
1977	$19,340	$13,809	10.9%	4.8%
1978	22,115	14,702	14.3	6.5
1979	25,708	15,731	16.2	7.0
1980	30,476	17,081	18.5	8.6
1977 to 1980 Per Annum Growth			16.4%	7.3%
1981	$35,428	$18,112	16.2%	6.0%
1982	39,512	19,053	11.5	5.2
1983	42,600	19,783	7.8	3.6
1984, Projected	47,712	21,359	12.0	8.1
1980 to 1983 Per Annum Growth			11.8%	5.0%
1980 to 1984, Projected Per Annum Growth			11.9%	5.7%

Source: National Science Foundation, Research and Development Industry, 1983, forthcoming. Rates of growth and conversion of current dollars to 1972 dollars (using GNP implicit price deflators) provided by the author. Projection for 1984 from the 12 percent increase over 1983 indicated in Science Resources Studies Highlights, NSF 84-329, October 15, 1984.

III

It is easy for naive or biased investigators to claim that the tax credit has contributed to growth in R&D, for company-funded R&D has been growing. The rates of growth, however, have been declining. They were 16.2 percent in 1981, the first year (or half-year) of the credit, 11.5 percent in 1982, and 7.8 percent in 1983, to a total of $42.6 billion in that year, as shown in Table 1.

The rates of growth were generally higher, and rising, before the tax credit was instituted: 14.3 percent in 1978, 16.2 percent in 1979, and 18.5 percent in 1980. With adjustment for inflation, the rates of growth for the three years preceding the credit were 6.5 percent, 7.0 percent, and 8.6 percent. With the credit, from 1981 to 1983, real rates of growth were 6.0 percent, 5.2 percent, and 3.6 percent. The per annum real growth from 1977 to 1980 was 7.3 percent, while from 1980 to 1983 it was only 5.0 percent. Inclusion of projected expenditures for 1984 raises the real post-tax credit growth rate to 5.7 percent, but that is still less than the rate of growth before the credit became effective.

Sober analysis offers little, if any, hard evidence of much increase in real R&D spending as a consequence of the credit. The Division of Policy Research and Analysis of the National Science Foundation funded separate projects by Edwin Mansfield of the University of Pennsylvania and by this author to evaluate the R&D tax credit shortly after it was instituted.[1] Mansfield, a distinguished scholar in the area of technological change and innovation, concluded on the basis of surveys and other analysis: "In all countries we studied, R&D tax credits and allowances appear to have had only a modest effect on R&D expenditures. In the United States, Canada, and Sweden, the results are quite similar, each of these R&D tax incentives having increased R&D expenditures by about one percent. . . . In all of these nations, the increased R&D expenditures due to the tax incentives seem to be substantially less than the revenue lost by the government. . . . In each country, there was substantial evidence that these tax incentives resulted in a considerable redefinition of activities as R&D, particularly in the first few years after the introduction of the tax incentive."[2]

TABLE 2:
QUALIFIED RESEARCH AND EXPERIMENTATION EXPENDITURES BY USABILITY OF CREDIT, 1981

USABILITY	QUALIFIED EXPENDITURES 1981	BASE 1980	GROWTH OVER BASE
	(Millions of Dollars)		(Percent)
Full Use of Credit	$ 9,221	$ 6,576	40.2%
Partial or Zero Use	4,220	3,006	40.4
Total	13,440	9,583	40.3

Source: U.S. Treasury Office of Tax Analysis

My own work, which is still proceeding, has failed to uncover any clear evidence that the tax credit has increased R&D spending. One test I applied, for example, was to check in Office of Tax Analysis data to determine whether firms that could use the credit to full advantage—essentially those with sufficient current tax liabilities against which the credit could be claimed—showed a higher rate of growth of R&D spending than those that did not have such current liabilities. The rates of growth, as shown in Table 2, were indistinguishable.

Another test of whether the R&D tax credit was having any effect was to compare differences in R&D spending for firms that would have been above and below base for the years 1976 to 1980, before the tax credit went into effect, and the years 1981 and 1982, when the credit was operative. In the later years an effective tax credit should have increased expenditures for firms over base and, if anything, reduced them for firms below base. Thus, if the credit was effective it should have increased the growth of R&D spending where it was growing and perhaps decreased it further where it was falling. But using this test, there is no evidence that the incremental tax credit had an effect. The differences between the mean excess of R&D over base and the mean shortfall of R&D below base, as percentages of previous R&D, turned out to be no greater, and indeed somewhat smaller, in 1981 and 1982 than in the five years before 1981.[3]

Further evidence comes from a 1984 interview survey conducted by the Industry Studies Group, Division of Science Resources Studies, of the National Science Foundation. Only 33 percent of the surveyed companies, accounting for 22 percent of total company-funded research and development, stated that they were increasing R&D expenditures as a result of the tax credit.[4] This would hardly seem impressive in view of the possibility that even the 22 percent may be an upwardly biased measure, because self-interested respondents would be more likely to evaluate the impact of tax benefits favorably.

The initial surge in claims for the tax credit offers embarrassing evidence of considerable "creative accounting."

That firms, at least initially, claimed substantial increases in R&D for tax purposes is clear. The initial surge in claims for the credit offers embarrassing evidence of considerable "creative accounting." Thus, Office of Tax Analysis data indicate, as shown in Table 1, that qualified R&D spending reported by taxpayers increased by 40.3 percent in the latter half of 1981 over its 1980 base. Yet National Science Foundation data show total company funds for R&D growing by only 16.2 percent from 1980 to 1981, while the Compustat data indicate a 14.1 percent overall increase. If the firms included in the Compustat are limited to those with positive R&D growth to make them comparable to the Office of Tax Analysis sample, we still get a growth over base of only 21 percent, roughly half of what the firms claimed when they filed with the Internal Revenue Service. There is clearly a strong implication that many taxpayers classified as research and development expenditures, in 1981, activities that they did not include in calculating their 1980 base. Analysis of McGraw-Hill survey data collected on our behalf makes it clear that firms did indeed increase their reports of R&D eligible for the tax credit by more than the increases in total R&D.

IV

Some of the problems with the current tax credit are addressed in proposals for its extension by the U.S. Treasury and the Senate. In particular, there is some effort to narrow the definition of research and experimentation. This might reduce the amount of credit claimed for expenditures that have little or nothing to do with technological innovation. The Treasury has also suggested the possibility of indexing base period research expenses to the general level of prices, so that the credit would relate to real increases in R&D expenditures and not those stemming from inflation. At the risk of proving a devil's advocate, I would propose adding several other amendments.

First, the 100 percent growth limitation, which reduces the nominal credit to 12.5 percent for firms increasing their R&D spending most rapidly, should be eliminated. While the limitation does not apparently affect a large proportion of R&D, its negative incentive effects are considerable where it does come into play.

Second, the credit should be made refundable or converted into a direct subsidy. Aside from being aboveboard and allowing Congress and the public to see clearly what government encouragement of R&D is costing, a direct subsidy would exempt government support from the sometimes capricious effects of a tax system already saddled with numerous "incentives" that have less charitably been dubbed loopholes. Clearly, the current tax credit discriminates against firms that lack tax liabilities because they are chronically unprofitable, because they are still new and growing rapidly, or because of substantial indulgence in other tax-reducing activities.

Third, and most important, while retaining the incremental nature of the credit—which may in principle allow it to have a greater "bang for the buck"—we should eliminate the company-specific definition of the base. It is this feature that results in losses in future credits equal to the amounts gained in current credits and that thus may actually encourage some firms to reduce their R&D expenditures.

This provision could be changed by superimposing upon an initial company-specific base—say, the average of 1982, 1983, and 1984 qualified R&D expenditures—an adjustment, year by year, calculated from industry or national movements in R&D. Thus, if a firm were in an industry where R&D in 1985 grew by 10 percent, its base for calculating its tax credit for 1986 would be raised by 10 percent from its 1982–1984 average. The firm would then know that an increase in its current R&D expenditures in 1985 would contribute to raising the base and reducing future credits for all firms in the industry but would have a trivial effect in raising its own base and reducing its own future credits. (The industry should, of course, be defined sufficiently broadly so that no one firm would have a substantial effect on the base.) Having the base depend upon industry behavior rather than the company's own actions would achieve maximum incentive impact with minimal Treasury tax loss.

V

Even if the critical defects in the current law can be corrected, why should there be any tax credit or subsidy for the R&D expenditures of profit-seeking private firms? In general, a free-market system means a minimum of government intervention. As the Treasury has now recognized explicitly in its recent tax reform proposals, this argues against tax subsidies or incentives for business investment in general. In principle, business will invest in what it finds profitable. Companies should not be offered special tax advantages to invest in what otherwise does not appear profitable.

As I stated at the outset, R&D is admittedly another matter, to the extent that there are unusual positive "externalities"—that is, benefits that extend beyond the direct participants in economic transactions. That this is true for basic research is clear. It may also be true for applied research in those cases where the fruits in terms of industrial development and ultimate profit are a long way off.

But of some $42.6 billion in total company-funded R&D expenditures in 1983, according to National Science Foundation data, less than $1.7 billion went to basic research and only $11.2 billion to applied research.[5] Fully $29.8 billion fell in the category of "development," which in many if not most instances relates to converting research findings into profitable products. Should not such expenditures be left to the market test of profitability?

With regard to basic and applied research, where externalities may lead us to expect less than optimum private support, why not look to public support of nonprofit universities and research institutes or to direct government action? Much current research in agriculture, defense, and the basic sciences is, after all, not done by private business.

Nonbusiness, nondefense research, which enjoys little of the lure or sustenance of private profits, cries out for additional support. If we are to encourage research and experimentation—and we probably should—it is there that public funds are needed. Private business should be left free to concentrate on R&D spending that seems profitable without receiving special tax advantages. ■

NOTES:

1. Findings reported in this article or elsewhere are, of course, those of the author and do not necessarily represent the views of the National Science Foundation.
2. Edwin Mansfield, "Fiscal Policy Toward Industrial Innovation: An International Study of Direct Incentives for R&D," presented at Harvard Business School 75th Anniversary Colloquium on Productivity and Technology, 1984, pp. 28–29. See also Mansfield's "Statement to the House Ways and Means Committee on the Effects of the Research and Development Credit," in Subcommittee on Oversight, House Ways and Means Committee, *Research and Experimentation Tax Credit*, 98th Cong., 2d sess., Aug. 2 and 3, 1984, 142–56.
3. Robert Eisner, Steven H. Albert, and Martin A. Sullivan, "Tax Incentives and R&D Expenditures," *Leading Indicators and Business Cycle Surveys*, ed. Karl A. Oppenländer and Günter Poser (Aldershot, England: Gower Publishing Company, Ltd., 1984), 385–419. Reprinted in *Research and Experimentation Tax Credit*, op. cit., see Table 3.22, p. 124. A shorter version appeared in the *National Tax Journal*, as "The New Incremental Tax Credit for R&D: Incentive or Disincentive?", June 1984, 171–83.
4. *Science Resources Studies Highlights*, (Washington, D.C.: National Science Foundation, Oct. 15, 1984), 84–329.
5. *Research and Development Industry, 1983*, (Washington, D.C.: National Science Foundation, forthcoming).

Robert Eisner replies:

In my article I declared that the current tax credit for research and development "has proved something of a monstrosity, costing the U.S. Treasury some $1.5 billion per year with no clear payoff." I stand by that statement.

F. Peter Boer is correct in stating that many factors bear on levels of R&D expenditures. As I pointed out in my article, there is little or no evidence that the tax credit has been significant.

Boer asserts that the real rate of growth in business R&D spending was 8 percent in 1984. But it was down to 3.6 percent in 1983. If business decisionmakers were paying attention to the credit, they might well have held down R&D expenditures in earlier years to offer a lower base for claiming a tax credit later. In any event the per annum real growth over the four years prior to the enactment of the tax credit was 7.3 percent, while growth over all of the years since the credit was enacted was on the order of 5.7 percent.

Boer's claim that in his own firm the R&D tax credit has been significant is strange, since W. R. Grace & Company has paid virtually no federal income taxes in recent years. Its provision for federal income taxes in 1982 was only $2.3 million, less than one percent of pre-tax profits. Over the three years from 1982 to 1984, its federal income taxes totaled $19.5 million, only 2.5 percent of pre-tax profits. And at that, according to its annual report, the company sold various tax credits, totaling $53.2 million, which it could not use.

The "colleagues in other firms" to whom Boer spoke must have been either atypical or dissembling. The National Science Foundation interviews, which I cited, found that only 22 percent of total company-funded R&D was undertaken in firms which reported that they increased R&D spending as a result of the tax credit.

While the nature of the R&D tax credit is such that there was little reason to expect it to make much difference in R&D spending, and neither I nor other sober investigators could find much evidence that it did, I did not say that "tax subsidies make no difference." Business will invest in what it finds profitable after taxes. I argued that Congress should not generally distort business decisions to make otherwise inefficient investment profitable on the basis of tax considerations. That argument would apply to a replacement of the current defective credit with something that really did increase business R&D spending.

The fact is that peering through the "statistical microscope," which Kenneth M. Brown ascribes to me, did not reveal any clear evidence that the credit was effective. I can now add to the report in my article new Office of Tax Analysis data for 1982. They show that firms able to use the credit increased R&D spending in 1982 by 35.8 percent over base. Companies whose lack of tax liabilities prevented them from taking advantage of the credit increased R&D spending by 36.1 percent over base. I don't know what microscope could read into these data evidence that the tax credit was effective.

I have not, as Brown suggests, advocated government grants to private companies for commercial R&D. As to the "thousands of innovative small firms that use the tax credit," over 80 percent of company-funded R&D in 1982 was done by firms with more than $100 million in net sales. Fifteen companies, in fact, accounted for about half of all business R&D spending in 1984. IBM and General Motors, at the top of the list, certainly undertook their R&D spending for underlying competitive reasons, and that was as it should be.

I agree fully with Kenneth McLennan that "A more neutral, broad based, low rate tax system would encourage investment to flow toward its most productive use." With tax reform again in the air, this is hardly the time to make it less neutral with a new "permanent" R&D tax credit.

PEER REVIEW AND THE PUBLIC INTEREST

The emergence of "scientific pork barreling" is an indication that peer review as it presently operates is not a wholly adequate means to determine priorities for the allocation of government research funds. While peer review is arguably the most effective means for the useful allocation of research funding within disciplines and over the short term, it has deficiencies as a process for determining broad and long-term science policies.

Peer review tends to perpetuate the status quo as regards scientific institutions, programs, and concepts. This tendency is accentuated as funding becomes more limited. With the passage of time, pre-existing funding patterns become firmly fixed within established research institutions and within the scientific enterprise as a whole in the absence of the formation of new institutions. Existing distributions of funding become accepted as the normal pattern, sanctified by custom. Circumventing peer review by "pork barrel" recourse to the political process is a sign of desperation and surely not the best way to remedy these deficiencies. New mechanisms and processes are needed to:

1) Systematically set aside a portion of research funds for the support of novel, if risky, concepts.

2) Systematically bring additional

Mr. **Hayes**. Thank you very much. I suppose that's what the clash between you and the gentleman to your left is. Let's think of it as a sophisticated Morton Downey, Jr. program as we go along with the rest of our panel.

Dr. Womack?

STATEMENT OF E. ALLEN WOMACK, JR., VICE PRESIDENT OF RESEARCH AND DEVELOPMENT DIVISION, BABCOCK & WILCOX, ALLIANCE, OHIO

Dr. **Womack**. Thank you, Mr. Chairman. My name is Allen Womack. I am Vice President for the Research and Development and Contract Research Divisions of Babcock and Wilcox, which is a unit of McDermott International.

I am also currently serving as Chairman of the Federal Science and Technology Committee of the Industrial Research Institute, which is a private national organization of managers of industrial R&D for over 250 of the major corporations in the United States. All of these corporations carry out continuing programs in industrial research, and I am a working R&D laboratory executive.

Dr. Lawrence and Professor Eisner have already spoken eloquently on R&D tax policy, and I have had the opportunity to see Mr. Eizenstat's remarks in draft and find myself in broad agreement with him.

Rather than attempting to dwell on the details of this subject in which I am not expert, I would offer you a couple of remarks which I find interestingly apropos to the discussion which took place after your last panel.

You are all well aware of the problems that we face in international competitiveness, watching international competitors produce less expensive higher quality goods and take over the lion's share of our market.

The reasons for this situation, of course, are fairly complex. There does seem to be a consensus that something has changed in our ability to convert good science to good products and sell them. The United States still is producing good science, although we have no reason to be complacent about that.

Somehow, however, the clutch seems to be slipping between the engine and the drive wheels, the engine of science and the drive wheels of the economy.

We've watched our competitors from abroad take developments and innovations of U.S. science and make large, successful and profitable industries out of them, producing goods which are sold back to us here.

We in industry have a lot to do with solving that problem. In fact, I believe it is and should remain primarily our responsibility within the private enterprise system. We have to work on such issues as being more global in our thinking, putting more effort into learning good ideas, making better use of the universities, federal laboratories and other private industrial organizations, and we simply need to work harder and smarter in an increasingly competitive environment.

We need to abate our preoccupation with short-term games that can be had with mergers, acquisitions and organizational restructuring and put more emphasis on fundamental productivity and the ability to produce higher quality goods and services at lower costs or as Dr. Caulder said earlier, "making products instead of making deals."

Clearly, I believe that private industry's actions have to be at the heart of the solution to this crisis, but I believe equally that the Federal and state governments have an essential and enabling role to play in encouraging and catalyzing the right actions within the private sector.

Of course, we have to recognize that the spirit of free enterprise, and entrepreneurialism is still very much alive in the United States industry, and every day thousands of managers and business leaders go to work determined to produce more goods which are attractive to the marketplace.

However, we've already noted that the front end of the technology production process basic science still seems to be in reasonably good shape, although there has been some discussion, pro and con on that this morning. But between those inventing and those selling lies a process of development and marketing which requires risk, and investment.

Our successful international competitors appear to have capital costs for investments of this type which are but a fraction of the costs of the investment in the United States. So long as this condition exists, the level of the activity and the technology to market phase of the American economy will be restrained.

I believe that the first order of business to correct this broad problem is to take those steps which serve to reduce the imbalance in the cost of capital for the investment in new technology, new products, and productivity. That means coordinated and serious actions by the Federal Government which encourage private investment as much as they now encourage consumption and increase the private savings rate in the economy. An R&D tax credit is a single action which should be consistent with the foregoing recommendation.

The Subcommittee asked for suggestions on improving the current credit. The effectiveness of the present structure could be substantially improved. The two previous speakers have already spoken to many of the points that I make in my written remarks, points such as the fact that the credit lacks certainty and consistency, the credit was provided a limited life, its life has been extended several times for short periods.

Also, we note that the rules are regularly amended to reduce the amount of the benefit. Unfortunately, this is a product of the current tax environment. What is an incentive one year is a tax avoidance scheme the next.

The above drawbacks can be corrected by establishing a permanent credit that would be available to corporations that maintain a consistently high level of R&D.

An alternative would be to provide credits to corporations to the extent their R&D expense exceeds a certain percentage of sales. The different R&D requirements of each industry would be recognized by using the industry average as a base. Credit would be earned on the R&D performed in excess of this base ration, and this way a corporation would not be penalized for maintaining a high level of activity and the base could be adjusted at frequent, determined intervals.

But beyond the R&D credit I think it is essential to deal with capital availability by adopting a reduction in the cost of capital and the encouragement of private savings as a broad objective of the Federal tax and spending policy, and taking the hard actions necessary to bring about the desired results.

Since I am neither an economist nor a legislator, I will not attempt to prescribe a detailed program for this. The specific recommendations of the Council on Competitiveness, the writings of Presidential Advisor Boskind and the work of the American Council of Capital Formation and others appear to me to offer reasonable specific steps.

If that recommendation comes as no surprise to you, then I'm sure the second one won't either. We must improve the level of literacy in science and technology among our young people.

There is plenty of evidence that for the great majority of our school children, science and technology remain subjects to be avoided, mysteries unexplained, something that they can get by without, and if I may say so, a joy unperceived.

It is not surprising that our post-graduate schools in science and technology are less and less hosts to American citizens and more and more are training the best and the brightest of the citizens of those countries which are our competitors in international trade.

It is no wonder that we find increasing difficulty obtaining functionally literate workers and managers for operations requiring the level of technical skills needed in today's world. It is no wonder that we find it increasingly difficult to reach political consensus on issues which involve complex technologies such as nuclear power regulation, acid rain, and the like.

It is time to recognize that the profession of educating our young people deserves dignity and compensation commensurate with its importance and its difficulty.

Should Federal support of college and post-graduate education be restored at earlier levels? Most decidedly. But as with the R&D tax credit, this action alone will not be sufficient without primary attention to pre-college education.

You requested thoughts on other cost-effective ways to stimulate R&D and its application in commerce. There are a number of areas in which the Federal Government can immediately and directly influence private innovation. These include intellectual property law, antitrust legislation, and of course the Government's role as a purchaser of goods and services.

I believe that pooling of talent and resources in intercompany and inter-institutional alliances is both efficient and necessary to address the problem of dwindling resource availability. The initiatives of the Congress and the Department of Commerce to relax barriers to cooperation among industrial participants are encouraging and helpful, and I urge you to address all aspects of the antitrust law in the context of today's global economy to assure at least that barriers to cooperation are removed where they are no longer necessary to protect adequate competition.

I am also encouraged by actions taken by the Congress to encourage broader dissemination of ideas and technology created within Federal programs and Federal laboratories to private industry.

Finally, let me close with a few remarks on the Federal Government's role as a purchaser. This a source of immense power to address the problem before us. With all that power, there will be a tendency to reach for quick solutions by attempting to pick out the winners among undeveloped technical ideas and providing them with funding to help commercialization. There are certainly a number of areas where this is a legitimate action.

However, the market economy will ultimately choose from among the successful commercial products. It is for that reason that I have placed the operating environment of industry and attention to capital availability and education ahead of direct Government program funding and priorities for Federal actions.

Nonetheless, the recommendations in the National Academy of Sciences for the management of the Federal Science and Technology budget deserve to be implemented, and I hope that they will be. I sincerely hope that other cross-cutting actions include a careful look at Government purchasing policy in high technology efforts. You have already had a long discussion about that this morning with the representative of Apple Computer.

It is discouraging to me in light of the seriousness of these discussions to see even occasional Government purchasing decisions send U.S. tax dollars abroad for high technology services and products when these dollars could be used to stimulate innovative action in U.S. companies.

In the case of our foreign competitors, I rarely see that action on the part of their government. In fact, local content is usually a go/no-go requirement for us to operate there.

Viewing Government purchasing policy and actions in the light of the need to stimulate research and innovation should be a very cost effective and immediately helpful action.

I appreciate the opportunity to address the Committee. I want to assure you that the R&D managers in American industry are as earnestly concerned about this problem as you are. I hope that these observations will be of some help.

Thank you.

[The prepared statement of Dr. Womack follows:]

REMARKS BEFORE HOUSE SUBCOMMITTEE ON SCIENCE, RESEARCH AND TECHNOLOGY

Stimulating Investment in Research and Development

May 18, 1989
by E. Allen Womack, Jr., Vice President,
Research and Development, Babcock & Wilcox

Good morning. My name is Allen Womack. I am vice president for the Research and Development and Contract Research Divisions of the Babcock and Wilcox company, a unit of McDermott International. I am also currently chairman of the Federal Science and Technology Committee of the Industrial Research Institute, a private national organization of managers of industrial research and development for over 250 of America's major corporations, all of which carry out continuing programs in industrial research and development. I am a working r&d laboratory executive.

Having given you all those credentials, I must insert the obligatory cautionary note that my perspective does not represent the result of a systematic policy formulation process within the organizations with which I am associated. Rather it reflects a combination of my own experience and those which my colleagues have shared with me in the matters which are before you.

I appreciate being included today on such an erudite panel and hasten to point out that the casual observer will have no difficulty picking out the non-expert among the four of us. Doctor Lawrence, Professor Eisner, and Mr. Eisenstadt have spoken eloquently on r&d tax policy and its effects, so rather than attempting to dwell on the details of that subject, I would offer you first the context of a few more general thoughts on the broad matter of concern of this committee and to many of us in United States industry. This is, of course, the apparent displacement of United States industry by overseas competitors in the manufacture and supply of commercial goods employing high technology.

You all know the story well. Once pre-eminent in bringing the fruits of science to market, we have watched as international competitors produced less expensive and higher quality goods in consumer electronics and other fields, and proceeded to take over the lion's share of our own United States market, in many cases entirely driving out United States producers. Accompanying these symptoms are perceived slowdowns in U.S. productivity growth, a serious negative balance of trade, and other symptoms of a malaise in the primacy of United States commerce in the world economy which goes under the name of "the U.S. competitiveness crisis." Jobs, profits, and national pride have gone overseas in large sectors of our economy and it is high time that we act on the problem.

As with most issues of large scale, the reasons for this situation are multiple and complex. There does appear, however, to be a consensus that something has changed in our ability to convert good science into good products and sell them. The U.S. is still producing good science, although we have no reason to be complacent about this. Somehow, however, the clutch seems to be slipping between the engine of science and the drive wheels of the economy. In fact, we watch our competitors from abroad take the developments and inventions of U.S. science and make large successful and profitable industries out of them, producing goods which are sold back to us here. As a manager whose primary day-to-day responsibility is to convert scientific knowledge and results into successful business results, I have thought a lot about this and I've talked with many others who are in the same boat.

We in industry have a lot to do to remedy this situation. In fact, I believe that it is and should remain primarily our responsibility within our private enterprise system. We need to work on such issues as being more global in our thinking and putting more effort into learning good ideas from beyond our own borders. We need to temper our independence and competitive spirit somewhat to make better use of our universities and federal laboratories and other private industrial organizations. We need to work harder and smarter in an increasingly competitive international environment. We need to abate our preoccupation with the short term gains which can be had with mergers, acquisitions, and organizational restructuring, and put more emphasis on fundamental productivity and the ability to produce higher quality goods and services at lower cost.

Clearly, I believe private industry's actions must be at the heart of a solution to this crisis. I believe equally that our federal and state governments have an essential and enabling role to play in encouraging and catalyzing the right actions within the private sector. Just as taking these actions will require private industry to reexamine some of its basic cultural tendencies, the actions that I will call for below will require an unusual degree of coordination and cooperation within the federal government.

First, we need to recognize that the spirit of free enterprise and and entrepreneurialism is still very much alive in United States industry. Every day thousands of managers and business leaders go to work determined to produce more goods which are attractive to customers and to do a better job of bringing them to market. We have already noted also that the front-end of the technology production process, basic science, still seems to be in reasonably good shape. Between those inventing and selling lies a process of technology development and marketing which requires risk and investment. Investment is a competitive process. Each of us wants the highest possible return for his savings. The amount of investment capital which is available to fuel the research, development and application process is one of the factors which restricts the rate at which improvements are made, at which new products are tried, at which new science is brought to bear on old processes and products. At some point in deciding whether or not to improve a process, add a quality improving feature, or develop a novel product, each technical manager and production manager and marketing manager thinks seriously about the risk and return of the actions he is considering taking. The cost, the capital investment which must be made, has to be weighed against the alternatives. If alternatives exist which provide lower risk and higher short-term returns, many investments will not be made.

Our successful international competitors appear to have capital costs for investments of this type which are but a fraction of the costs of investment in the United States. So long as this condition exists, the level of activity in the technology-to- market phase of the American economy will be restrained. I believe that the first order of business to correct this broad problem is to take those actions which reduce the imbalance in the cost of capital for investments in new technology, new products, and productivity. This means coordinated and serious actions by the federal government which encourage investment as much as they encourage consumption, increasing the private savings rate in the economy. This will require actively and aggressively lowering the level of federal debt which now burdens our economy and which competes for investment dollars. Many private firms simply cannot afford to carry through expensive investment programs which take five years or more to recover their costs and begin paying back the capital investment which has been made. A competitor with a lower cost of capital can view this decision differently. A patient investment in his case may not jeopardize the firms cash flow and place it at risk of takeover and acquisition.

An r&d tax credit is a single action which should be consistent with the foregoing recommendation. The subcommittee asked for suggestions on improving the current credit. The effectiveness of the present structure could be substantially improved. The current credit requires an increase in research expenditures each year. This is unrealistic for many companies as their business is cyclical and cannot support constant annual increases in r&d expenditures. Thus, the credit may only provide an incentive for a few years before the base r&d spending of prior years becomes a limit. Once this occurs, there is an incentive to reduce the level of research to establish low base spending years for subsequent increased r&d

expenditures. In addition, the credit lacks certainty and consistency. When the law was enacted, the credit was provided a limited life. Subsequently, its life has been extended several times for short periods.

Not only is the continued existence of the credit uncertain, but the rules are regularly amended to reduce the amount of the benefit. Unfortunately, this is a product of the current tax environment. What is an incentive one year, is a tax avoidance scheme the next. Almost as soon as a tax benefit is provided, Congress begins to amend the law to reduce it. It is impractical to expect a corporation to establish a significant long term r&d program based upon a credit with an indeterminate life and a constantly fluctuating benefit.

The above drawbacks can be corrected by establishing a permanent tax credit that would be available to corporations that maintain a consistently high level of r&d. An alternative would be to provide credits to corporations to the extent their r&d expense exceeds a certain percentage of sales. The different r&d requirements of each industry would be recognized by using the industry average as the base. Credit would be earned on the r&d performed in excess of this base ratio. In this way a corporation would not be penalized for maintaining a high level of activity. The base should be adjusted at infrequent predetermined intervals.

Beyond an r&d credit, capital availability must be dealt with by adopting the reduction of the cost of capital and the encouragement of private savings as a broad objective of federal tax and spending policy and taking the hard actions necessary to bring about the desired results.

I am neither an economist nor a legislator, so I will not attempt to prescribe a detailed program for the implementation of this difficult goal. The specific recommendations of the Council on Competitiveness, many of the writings of Presidential Advisor Boskind, and the work of the American Council on Capital Formation offer what appear to me to offer reasonable specific steps to achieve this overall essential goal of reducing the cost of capital within the American industrial economy.

If that recommendation comes as no surprise to you, then I'm sure the second one will not either. We must improve the level literacy in science and technology among our young people.

A few days ago, Professor Stephen Gould delivered a commencement address at Duke University entitled, "The Republic Needs Science." In this speech he drew a comparison between the suppression of intellectual inquiry at the time of the Inquisition (exemplified by the trial of Galileo), and the situation which exists today in the United States. "Outrageous" you say -- "after all we have done to protect intellectual freedoms?" Yes, unless you consider that failing to provide the voting and working population of our democracy with a functional understanding of the technological principles on which modern society is founded leads to exactly the same result. Such a science-naive society will leave the economic enterprise of the United States without the people needed to carry out the objective of re-building and maintaining our competitive position.

While, thankfully, there are a number of good success stories in the United States today, there is plenty of evidence that, for the great majority of our school children, science and technology remain subjects to be avoided, mysteries unexplained, something that they can get by without and, if I may say so, a joy unperceived. It is not surprising that our post-graduate schools in science and technology are less and less hosts to American citizens and more and more are training the best and the brightest of the citizens of those countries which are our competitors in international trade. It is no wonder that we find increasing difficulty obtaining functionally literate workers and managers for operations requiring the level of technical skills needed in today's competitive world. It is no wonder that we find it increasingly difficult to reach political consensus on issues which involve complex technology such as nuclear power regulation, acid rain, and the like.

Unless we act, this situation is only going to get worse. We are graduating 700,000 per year from high school who are not functionally literate and another 700,000 per year never finish high school at all. Those who do graduate fare very poorly relative to their international peers in tests of scientific comprehension. These citizens and voters are going to have an almost impossible task finding rewarding work in today's society and participating effectively in the political decisions which will confront them during their lifetimes.

It is time to recognize that the profession of educating our young people deserves dignity and compensation commensurate with its importance and its difficulty. This is a nationwide problem. Bold federal leadership is going to be needed to correct it. The best and the brightest of our young college graduates are not going to choose the difficult career of teaching until the rewards for doing so become more competitive with those for choosing other paths including science in private industry, law, investment banking, medicine, and the other professions.

I believe that the teacher compensation issue should be addressed at

the national level, and decisively. At the same time, I believe that our local schools should be held to high standards; standards which require and encourage the creation of scientifically literate graduates, the kind we have to have to restore the competitiveness of our society. I would encourage you to consider the Project 2061 program recommendations of the American Association for the Advancement of Science.
Should federal support of college and post graduate education be restored to earlier levels? Most decidedly. But as with the r&d tax credit, this action alone will not be sufficient without attention to pre-college education.

You requested thoughts on other cost-effective ways to stimulate r&d and its application in comerce. There are a number of areas in which the federal government immediately and directly influences private innovation. These include intellectual property law, antitrust legislation, and of course the government as a purchaser.

I believe that pooling of talent and resources in intercompany and inter-institution alliances is both efficient and necessary to address the problem of dwindling resource availability. The initiatives of the Congress and the Department of Commerce to relax barriers to cooperation among industrial participants are encouraging and helpful. I urge the Congress to address all aspects of antitrust law in the context of today's global economy to assure at least that barriers to cooperation are removed where they are no longer necessary to protect adequate competition in a free market which includes players from around the globe.

I am also encouraged by actions taken within the Congress and the Administration to encourage the broader dissemination of ideas and technology created within federal programs and federal laboratories to private industry. The Technology Transfer Act of 1986 and the activities which it has generated certainly encourage the kind of institutional cooperation and good utilization of available resources which is needed to stimulate competitiveness.

Finally, let me close with a few remarks on the federal government's role as a purchaser. This is a source of immense power to address the problem before us. The government directly purchases and funds approximately half of all research and development performed in the United States. Perhaps even more important, federal acquisition frequently provides the initial market for high technology innovations which can later become elements of commercial products.

With all this power, there will be a tendency to reach for quick solutions of our competitiveness problem by attempting to pick out the winners among undeveloped technical ideas and providing them with funding to help commercialization. There are certainly a number of areas where this is a legitimate federal action. These are areas in which the product or innovation produced is needed to achieve one of the objectives of government, that is to do for our ourselves collectively what we cannot do for ourselves individually. These objectives include the national defense and the protection of the environment, the basic science process which is distant from commercial enterprise, and other areas well known to you. I think this kind of direct support must continue in a judicious way. The market economy will ultimately choose from among the successful commercial products. It is for this reason that I place attention to the environment in capital availability and education ahead of direct government program budgeting in priorities for federal action. Nonetheless, the recommendations of the National Academy of Sciences for the management of the federal science and technology budget deserve to be implemented by the Administration and Congress, and we are all looking forward to a more vigorous cross-agency rationalization by Presidential Advisor Bromley and the Department of Commerce.

I sincerely hope these actions include a careful look at government purchasing policy in high technology efforts. It is certainly discouraging in the light of the seriousness of these discussions to see even occasional government purchasing decisions send U.S. tax dollars abroad for high technology services and products when these could be used to stimulate innovative action in U.S. companies. Please understand, I am not a xenophobe. No one in a global economy can afford to be. However, as I observe the actions of national governments of our competitors, I rarely see them awarding high technology procurements to U.S. companies when local companies could do the job. In fact, local content is almost always a go/no-go requirement for American companies which wish to do business abroad. I hope that the Congress and the Administration will implement more effective policy in this regard. Viewing government purchasing policy and actions in the light of the need to stimulate research and innovation should be a very cost effective, and immediately helpful, action.

I appreciate this opportunity to address the Committee. I want to assure you that research and development managers in American industry are as earnestly concerned about this problem as you are. I hope that these observations will be of some assistance in achieving federal actions which provide the environment within which we can together reestablish the vigor of an innovative and competitive economy within the global market.

Thank you.

Mr. HAYES. We'll hear now from Mr. Eizenstat.

STATEMENT OF STUART E. EIZENSTAT, COUNSEL TO THE COUNCIL ON COMPETITIVENESS AND COUNCIL ON RESEARCH AND TECHNOLOGY, WASHINGTON, D.C.

Mr. EIZENSTAT. Thank you, Mr. Chairman.

I am testifying on behalf of the Council for Competitiveness, an organization of chief executives from business, labor and higher education, and on behalf of the Council on Research and Technology, CORETECH, which is a corporate university high-tech coalition.

The Council on Competitiveness does not endorse specific legislation, while CORETECH does.

I am going to address, if I may, Mr. Chairman, four topics which form a major part of a coherent strategy to continue to expand research and development of the United States.

First, enactment of a permanent R&D tax credit with a modified base period, and coverage for the first time of start-up ventures, as well as a permanent basic research credit to encourage greater cooperation between corporations and universities; enactment of a compromise of a long-standing 861-8 regulations controversy which acts as a significant barrier currently to R&D; full funding of the academic research facilities modernization provisions established by the NSF Authorization Act of last year, which this Committee took the leadership position in passing, so that cutting edge research can be done in modern facilities on university campuses and non-profit institutions; and the improved training of America's scientific work force.

A few very brief introductory remarks before touching on each of these four very briefly.

More R&D, Mr. Chairman, is not an end in itself, but rather a means to stimulate innovation, which in turn is a key ingredient in boosting productivity and competitiveness. This country has no longer a monopoly on quality. We cannot compete based solely on unit labor costs. We have to do so by being on the cutting edge of new product development, and that heavily depends on more R&D.

It is important to emphasize why the Federal Government has an important role in fostering more R&D. Private firms will not perform all the R&D which it is in this country's interest to have them perform because of the inherent risks of R&D, the low rates of commercial return, and the long lead times involved.

It is well established, Mr. Chairman, that society get somewhere between two and three times the payback from a successful R&D project than the company performing the research.

My last introductory point is this: Consistency is absolutely critical in the implementation of research and development policy. For Government incentives to be effective, private industry requires assurance that they do not now have that the incentives will remain in place throughout the course of a project.

I urge the Congress, Mr. Chairman, with this Committee in the lead, to adopt a comprehensive program to stimulate research and development, first on the permanent R&D credit and basic university research credit. The rate of increase of U.S. productivity has declined in recent years. The U.S. spends a smaller percentage of its GNP on non-defense R&D than its major competitors, and to stimulate additional non-defense R&D the R&D tax credit and the university basic research credit should be made permanent.

Since first enacted in 1981, the R&D credit has been subject to a number of short-term extensions and to cutbacks as well. From its original 25 percent figure it was cut back to 20 percent and as Mr. Lawrence indicated, a deductional disallowance was passed in 1988.

We live in a global economy, Mr. Chairman, and other nations provide substantially stronger tax incentives for research and development. For example, 25 percent of all the tax benefits in the Japanese tax system are allocated to research and development incentives.

To the extent that we provide less than our major competitors, our own domestic companies operate at a competitive disadvantage. Some economists including Mr. Eisner have criticized the current base period for undercutting the full incentive effect on the credit.

Responding to his critique, CORETECH supports the work of the Treasury Department in developing a new fixed based period. Under this proposal incorporated in the Jenkins-Frenzel Bill, H.R. 1416, there is a fixed base period for a company's 1984 to 1988 expenditures. The base is then indexed to the growth of the nation's GNP.

This bill has a number of additional advantages. Start-up ventures would be covered for the first time, the new R&D credit would have a 7 percent credit for so-called "slow growers" and in addition there would be a permanent extension so that certainty could be provided.

I would like very briefly to mention the basic research credit which has not been discussed. This is intended, Mr. Chairman, to encourage corporate university cooperation. One of the great advantages the Japanese have in the world market is how quickly they are able to translate basic research into commercial products.

In our country, it takes on average a much longer time for this process to occur. A significant reason for that is that the Japanese have the advantage of very close corporate-university cooperation in the research field.

The basic research credit first passed in 1986 is designed to close this gap. If corporations are involved, Mr. Chairman, and helping to structure the basic research products carried on by universities and non-profit institutions, we believe those products and projects will have more of a marketplace orientation.

Second are the 861-8 regulations. Tax regulations issued in 1977 require U.S. corporations with foreign operations to allocate a percentage of their domestic R&D expenditures to income earned abroad. The effect is to deny a full deductibility of R&D costs to U.S. companies and to impose a penalty on domestic research and development for companies in an excess foreign tax credit situation.

The effect of this, Mr. Chairman, is to encourage our own companies to relocate R&D efforts abroad. We are the only company in the industrial world which discourages the conduct of R&D in this manner. Every other industrial nation permits a full deduction of corporate domestic R&D against their own domestic income.

Congress, recognizing the unfairness of these regulations has passed four moratoria since 1977. It is important that we have a permanent solution. Treasury's own study concluded that the regulation would reduce R&D conducted within the United States by an amount equal to the revenue raised by the new regulation.

Fortunately, there is a solution. In 1987, the Treasury, the Ways and Means Committee and the Finance Committee came up with a so-called 67 percent compromise, which permits 67 percent of a corporation's U.S. R&D expenditures to be set aside and deducted against domestic source income. President Bush's budget amendments specifically include a 67 percent compromise dating back to the time of the last expiring moratorium, and we, CORETECH, strongly endorse that solution.

I would also add that President Bush's budget includes the permanent extension of R&D in university basic research credits.

Third is full implementation of the academic research facilities modernization provisions this Committee had so much to do with having passed to begin with. The authorization has been passed, Mr. Chairman, there is no appropriation, there is no request for appropriation in the Bush budget, this Committee has demonstrated its commitment to modernizing academic research facilities.

In your own report accompanying the bill you concluded that $10 billion in expenditures over the next ten years was required to modernize the crumbling buildings and obsolete equipment in various scientific facilities.

The simple fact is that we cannot conduct the most sophisticated research in outmoded and obsolete facilities. Indeed, the modernization shortfall every year is escalating. To reverse this downward spiral of academic research facility conditions, we urge full funding of the Act you did so much to help pass last year.

Fourth, and last, is training America's scientific and engineering work force. Our country's ability to expand its R&D is dependent upon the availability of skilled technical workers to carry out the necessary experiments. A well-trained science and engineering work force is essential if we are to become more competitive.

Yet, shockingly, there are between 1,300 and 1,800 engineering faculty positions in our own colleges which are vacant. The combined shortfall exceeds 18 percent of the necessary engineering faculty. In addition to the shortage of faculty, engineering schools are simply unable to attract sufficient numbers of qualified U.S. citizens into their graduate programs.

A decreasing percentage of U.S. students are interested in pursuing careers in engineering and science. Foreign students represent some 40 percent of the total enrollment in U.S. engineering graduate schools and receive more than half of the U.S. doctorates in engineering. Yet many of these foreign students return home to their own countries, as you would expect, rather than staying here and providing long-term benefits to our country.

The National Science Foundation found that approximately 60,000 of today's math and science teachers in our secondary schools are not fully qualified, and by 1995, which is just around the corner, the U.S. will need an estimated 300,000 additional secondary math and science teachers, and with fewer kids coming through wanting science and math, Mr. Chairman, where are we going to get the pool from?

This is not a problem of the future, however. It is a problem of today. We suggest that the Federal Government encourage programs to upgrade the skills of science and math teachers and create incentives for talented science and engineering students to become teachers.

The Federal Government should increase support for undergraduate and graduate education in science and engineering by reversing the loan/grant imbalance in undergraduate and graduate education.

It should expand programs to raise the percentage of women and minorities in these fields by graduate fellowships and research intern programs and that it stimulate career-long continuing education programs.

Even at time of severe budget pressures, Mr. Chairman, it is imperative that the Government find the means to support research and technology. By investing in R&D today, we will create a healthier, more vibrant, more competitive economy and we will get back many times fold the investment that the Government puts into R&D.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Eizenstat follows:]

STATEMENT OF

STUART E. EIZENSTAT
Powell, Goldstein, Frazer & Murphy

On behalf of The Council on Competitiveness

and

The Council on Research and Technology (CORETECH)

before the Subcommittee on Science, Research and Technology,
Committee on Science, Space, and Technology,
United States House of Representatives

Panel on
Stimulating Research and Development

May 18, 1989

Mr. Chairman and Members of the Committee:

Thank you for inviting me to testify before you today on methods of stimulating research and development in the United States. I am testifying on behalf of the Council on Competitiveness and the Council on Research and Technology (CORETECH). The Council on Competitiveness is an organization of chief executives from business, organized labor, and higher education, including representatives from many of the major corporations in the United States and the most prestigious educational institutions. It is headed by John Young of Hewlett-Packard. CORETECH was established in 1987 to increase the U.S. commitment to research and development. CORETECH is comprised of 51 major corporations, 78 universities, 7 independent research institutes, 17 trade and professional associations, and 9 affiliates. Both of the organizations care deeply about stimulating additional U.S. research and development. In some cases, there are slight differences in their areas of emphasis and I will attempt to indicate those in my testimony.

My testimony will address four specific topics which will provide an effective stimulus for the continued expansion of research and development in the United States:

o The enactment of a permanent research and development tax credit with a modified base period and coverage for R&D expenditures by start-up ventures to stimulate greater industrial research and development, and a permanent basic research credit to encourage greater cooperation between corporations and universities and basic research institutes.

o The enactment of the "67 Percent Compromise" solution to the long-standing 861-8 Regulations controversy, which is a significant barrier to R&D.

o The full funding of the Academic Research Facilities Modernization provisions established by the National Science Foundation Authorization Act of 1988 so that cutting edge research can be done at modern facilities on university campuses and at non-profit institutes.

o The improved training of America's scientific work force so that the U.S. has a sufficient number of well-trained scientists and engineers to perform research and development in the U.S.

By way of introduction, the Council on Competitiveness wishes to emphasize that these targetted efforts to stimulate research and development can be fully successful only in the context of sound macro-economic policies designed to bring down the Federal deficit to balance over the next four to five years.

The huge debt burden of the Federal government, the need to finance triple-digit deficits heavily from foreign investors due to the low U.S. savings rate, spending one of every seven Federal dollars just to pay interest on the debt, all work contrary to efforts to stimulate R&D and starve the government of the resources needed to encourage greater private sector R&D.

In addition, more R&D is not an end in itself, but rather a means to stimulate innovation in America, which is a key ingredient in boosting American productivity and competitiveness. We no longer have a monopoly on quality. We cannot compete based on unit labor costs. We must do so by being on the cutting edge of new product development--and that depends heavily on more R&D.

Likewise, it is important to emphasize why the Federal government has an important role in fostering more R&D. Private firms and institutions will *not* perform all of the R&D it is in our country's interest to have them perform because of the inherent risks in R&D, the low rates of commercial return, and the long lead times involved. It is well established that society gets two to three times the payback from a successful R&D project than the company performing the research, due to imperfect patent protection and the ripple effects of innovation. Therefore, if the government stimulates additional R&D at the margin, society as a whole benefits. It is estimated that two-thirds of the gains in productivity in the United States from

1929 to the current date resulted directly from technological innovations.

The last introductory point is this: consistency is critical in the implementation of research and development policy. Research and development looks to the future. Research projects often take years to complete. For government incentives to be effective, private industry requires assurance that the incentives will remain in place throughout the course of a project. Temporary and sporadic policies lack effectiveness in inducing the desired behavior of the private sector.

Congress should adopt a comprehensive approach to stimulating research and development. Research programs require facilities, people, projects, and funds. If you have a project, but no laboratory in which to work, or too few scientists and engineers to conduct the experiments, the project is doomed to failure. Accordingly, Congress should seek to ensure that a trained scientific and engineering work force is available for the conduct of research and development, that modern facilities capable of accommodating the most recent technological advances are in place, and that private industry has sufficient stimulation to fund the further expansion of our research and development efforts.

A PERMANENT R&D TAX CREDIT AND BASIC RESEARCH CREDIT

There is no question that the rate of increase of United States productivity has declined in recent years. The United States spends a smaller percentage of its gross national product on non-defense R&D than France, West Germany, or Japan. These two facts are clearly related. To stimulate additional non-defense research and development within the United States, the R&D tax credit should be made permanent. Furthermore, CORETECH feels strongly that the improvements and modifications to the R&D credit that are contained in H.R. 1416 and S. 570 should be enacted.

Strong support for making the R&D credit permanent is found on both sides of the aisle, as well as in the Administration. President Bush's budget for Fiscal Year 1990 specifically endorses a permanent extension of the 20 percent incremental R&D credit, with a modified base period to provide an enhanced center for R&D. Since it was first enacted in 1981, the R&D credit has been subject to a number of short-term extensions. Greater certainty is essential to stimulate the vigorous research and development critical to the innovation in technology and productivity that will maintain and enhance the United States' leadership in the world marketplace.

The R&D credit is the linchpin of the effort to stimulate research and development within the United States.

A study conducted in 1987 by two eminent economists, Martin Neil Baily and Robert C. Lawrence of the Brookings Institution, concluded that the R&D credit resulted in a 7 percent increase in research and development expenditures conducted by United States corporations. They further estimated that additional research and development has added $8 to $13 billion to the gross national product. Increases in the gross national product produce additional tax revenues. If the current 1 to 5 ratio of Federal tax revenues to the gross national product holds true, each incremental $8 billion in gross national product generates an additional $1.6 billion of tax revenue for the Federal government. Over time, the R&D tax credit will generate net revenue for the government.

In addition to increasing total R&D expenditures by approximately 7 percent, the Baily-Lawrence study concluded that corporations which qualified for the credit increased their R&D expenditure by an amount greater than corporations that did not qualify for credit. In 1983, for example, corporations which qualified for the R&D credit increased their research and development expenditures by 30.4 percent as compared to an 11.1 percent increase for corporations that did not qualify for the credit. The significance of that differential further demonstrates the effectiveness of the credit. So, too, it represented a large rise in R&D despite the most serious recession since the end of the Great Depression.

Yet, in the face of the success of the R&D credit in the U.S., it has been consistently cut back. In 1981, it was originally passed as a 25 percent incremental credit. The R&D tax credit cannot be taken unless a company exceeds the average of its past three years R&D expenditures. It was cut back to 20 percent and the definition of qualified R&D was tightened in the 1986 Tax Reform Act. In the 1988 Tax Reform Act, the credit's value was reduced by another one-sixth by passage of a 50 percent deduction disallowance. This is a perverse result at a time of increasingly fierce international pressures.

Other nations provide substantial incentives for research and development. Twenty-five percent of the tax benefits in the Japanese tax system are allocated to research and development incentives. France maintains a system of cash grants for research and development in addition to a research and development tax credit similar to the United States system. Ireland allows full deduction of R&D expenses in the year incurred as well as providing favorable capital allowances for machinery, equipment, and buildings for research and development. Furthermore, if R&D activities result in patentable products, Ireland exempts royalty income arising from the licensing of such products from tax. Canada provides a 20 percent flat rate tax credit for R&D activities while also permitting the immediate expensing of both current and capital expenditures for R&D purposes. West Germany provides a 20 percent direct cash payment on the first $170,000 and 7.5 percent on the balance spent in any given year on depreciable assets used for R&D purposes. In addition, West Germany allows full deduction of R&D expenditures in the year in which they occurred. These incentives are only a sampling of the substantial tax benefits available to support research and development expenditures throughout the industrialized world. To the extent that we provide less, our domestic companies operate at a competitive disadvantage.

Some economists have criticized the current base period for undercutting the full incentive effect of the credit, since a company's current year R&D is built into the rolling three-year R&D base average. Responding to that critique, CORETECH supports the work of the Treasury Department to develop a new fixed base period. Under their proposal, incorporated into the Jenkins-Frenzel bill (H.R. 1416) and the Danforth-Baucus bill (S. 570), there is a fixed base period of a company's 1984 to 1988 expenditures; the base is then indexed to the growth of the nation's GNP.

These bills have a number of additional advantages:

a. Start-up ventures would be covered for the first time. The current R&D credit covers R&D expenditures only for "existing" businesses. It was a major oversight not to cover new ventures, for whom the R&D credit would be of particular benefit.

b. The new R&D credit would have a 7 percent credit for companies whose R&D is increasing but not at the rate needed for the 20 percent credit. This "slow-grower's" credit would have a base 75 percent of the regular credit's base.

c. Some 10 percent more of the country's R&D intensive companies would be able to take advantage of the new credit compared to the existing one--covering some 80 percent of America's R&D companies.

A major feature of H.R. 1416 and S. 570 is the permanent extension of the basic research credit first passed in the 1986 Tax Act. The basic research credit provides an encouragement for corporations to contract out their basic research to universities and non-profit research institutes. Like the R&D credit, the basic research credit is also incremental and provides a 20 percent tax credit for basic research contracted to eligible institutions above a historic base period. No change would be made in the basic research credit except to make it permanent.

There is abundant evidence that one of the great advantages of the Japanese in the world market is how quickly they are able to translate basic research into commercial products. In our country it takes, on average, a much longer time for this process to occur. A significant reason for the Japanese advantage is the close corporate-university cooperation in Japan.

The basic research credit is designed to close this important gap. If corporations are involved in helping to structure basic research projects carried on by universities and non-profit institutions in the U.S., we believe that those projects will have more of a marketplace orientation and will lead to a shortened time period between basic research and commercialization.

CORETECH supports a permanent extension of the basic research credit to provide certainty and predictability in this important area.

861-8 REGULATIONS: ENACT THE 67 PERCENT COMPROMISE

Tax regulations issued in 1977 under Section 861 of the Internal Revenue Code require United States corporations with foreign operations to allocate a percentage of their domestic research and development expenditures to income earned abroad. Under the regulations, a decreasing amount of domestic R&D expenses can be set aside against domestic income, down eventually to 30 percent. The effect of these regulations is to deny full deductibility of R&D costs. Obviously, the inability to deduct research and development expenses incurred within the United States effectively imposes a penalty upon domestic research and development for companies in an excess foreign tax credit situation. While some tax theorists believe it appropriate to allocate expenses by reference to the source of the income generated by those expenses, the effect of denying United States companies deductions for research and development expenditures will be to encourage them to relocate their research and development efforts abroad. If, for example, a product sold in West Germany is allocated an R&D expense incurred in the U.S., the R&D might as well be conducted in West Germany, where a full deduction can be obtained. Such a relocation would be welcomed with open arms by the governments of other countries in the world. The United States is the only country in the industrial world that discourages the conduct of research and development in such a manner. Every other industrial nation permits a full deduction of their corporate domestic R&D against domestic income.

The controversy over the allocation of research and development expenditures to foreign source income began in 1977 with the issuance of proposed regulations by Treasury. Twelve years later the controversy still rages after Congress, on five separate occasions, imposed a moratorium on the effective date of those regulations, recognizing their unfairness. The last of these moratoria ended in May, 1988, leaving R&D intensive U.S. companies with foreign source income subject to the full brunt of the old, discredited 1977 regulations. A permanent solution is needed.

The purpose of these hearings is to identify those policies which will stimulate research and development in the United States. Pure common sense dictates that any policy which increases the cost of research and development discourages its conduct. Nothing is clearer than the fact that we must stimulate domestic research and development. Research and development conducted within the United States is most likely to be tailored to our domestic needs and to our domestic markets. When R&D moves abroad, jobs move with it.

Our history teaches us that research and development conducted within the United States produces substantial spin-off effects. Improving existing products and creating technologically innovative new ones generates benefits not only to the developer of the new or improved product but also to the users of that product and to others who find new applications for the technological innovation. The spin-off effects of research and development frequently are produced by people directly involved in the new technology--people at the site of the development. Accordingly, we must encourage United States companies to conduct their research and development within the United States.

Viewed from another perspective, boosting domestic research and development increases the critical mass of trained personnel within the United States and acts as a continuous magnet to attract foreign scientists and engineers to our shores. Research conducted within the United States trains United States scientists and engineers. It produces high wage jobs within our country.

Treasury's June 1983 study of the effect of the 861-8 Regulations, produced at the request of Congress, concluded that the regulations would reduce research and development conducted within the United States by an amount equal to the revenue raised. Treasury estimated that the regulation, if effective for 1982, would have increased the tax liability of United States' companies by $100 to $240 million. The study then estimated that United States research and development expenditures would have been reduced by $37 million to $260 million. The Treasury study was written to support the 861-8 Regulations and used conservative estimates of its adverse affects. A dollar for dollar reduction in United States R&D spending is nothing short of a disaster. One can hardly imagine a more perverse tax policy.

Even when viewed from a technical tax perspective, the 861-8 Regulations are inconsistent with the provisions of the 1986 Tax Act. The "Super Royalty" provisions of the Tax Reform Act of 1986 insure that United States corporations will be taxed within the United States on the value of the fruits of their domestic research and development efforts. Under the "Super Royalty" provisions, foreign income is recharacterized as domestic source income and taxed by the United States. Given that sourcing magic, artificially allocating research and development deductions to foreign source income puts a double-whammy on United States corporations; they cannot deduct within the United States the expenditures which generate United States source income. Accordingly, the very mismatching that the 861-8 Regulations were designed to eliminate is created by the combination of the 861-8 Regulations and the "Super Royalty" provisions.

Fortunately, the solution to the 861-8 Regulations disaster has already been developed. In 1987 Treasury, the Senate Finance Committee, and the House Ways and Means Committee, with industry support, agreed upon a solution to the 861-8 Regulations problem. In brief, the "67 Percent Compromise" reached permits 67 percent of a corporation's United States research and development expenditures be set aside and deducted against domestic source income. The remaining 33 percent of the research and development expenditures would be allocated as provided in the current 861-8 Regulations.

The Reagan and Bush Administrations have strongly endorsed a permanent solution to the 861-8 Regulations problem along the lines of the 67 Percent Compromise. President Bush's budget amendments specifically include a permanent 67 Percent Compromise dating back to the time of the last expiring moratorium. CORETECH strongly endorses that solution.

FULL IMPLEMENTATION OF THE ACADEMIC RESEARCH FACILITIES MODERNIZATION PROVISION

To conduct research, a scientist must have facilities in which to experiment. This Committee recognized that fact in initiating the University Research Facilities Revitalization Bill in the 100th Congress, led by Chairman Bob Roe. By passing the National Science Foundation Authorization Act of 1988, the House and Senate authorized the expenditure of $80 million in fiscal year 1989 for the modernization of academic research facilities. That authorization increased in subsequent fiscal years--$125 million in 1990, $187.5 million in 1991, and $250 million in 1992. Unfortunately, the authorization has not yet been followed by actual funding. Neither the Reagan nor the amended Bush budget for fiscal year 1990 contains funds for the modernization of academic research facilities either within or in addition to the proposed--and welcome--14 percent incremental increase in the National Science Foundation budget.

This Committee has demonstrated its commitment to modernizing academic research facilities. House Report 100-649 to the National Science Foundation Authorization Act of 1988 eloquently stated that:

> "Throughout our nation's history the health of our economy and the strength of our national defense has been coupled with that of colleges and universities. This country looks to its colleges and universities for both new knowledge as well as training for scientists and engineers. This linkage is truly unique. There is no coincidence that the U.S., with its foundation of academic research and training, has led the world in all measures of achievement in science and technology."

House Report 100-649 then concluded that $10 billion in expenditures over the next ten years was required to modernize the crumbling buildings and obsolete equipment in various scientific fields. The White House Science Council and the Bromley-Young report during the Reagan Administration came to a similar conclusion. Frank Press, the president of the National Academy of Sciences, has called for the expenditure of $1.25

billion per year for the next five years to replace crumbling and decaying facilities.

The simple fact is that we cannot conduct the most sophisticated and most productive research in outmoded and obsolete facilities. Our universities and non-profit research institutes cannot attract outstanding scientists and engineers if they must perform their research in out-of-date facilities. Moreover, young scientists and engineers must receive training on the most modern equipment, which often cannot be used in antiquated research facilities, if our country is to achieve the next generation of technological innovation.

Recent scientific breakthroughs have depended upon new instruments--new instruments which typically are more sophisticated and expensive than their predecessors. The scanning tunnel microscope for visualizing atoms and techniques such as capillary electrophoresis that can follow chemical changes in single neurons are exciting and open new worlds to explore, but they are expensive. Without state-of-the-art equipment and laboratories, progress will be slow and the best engineers and scientists will migrate to positions elsewhere, even abroad, that remain on the cutting edge..

The facility modernization shortfall is escalating. For every $1 spent on new construction, $2.50 was deferred. For every $1 spent on repair and renovation, $3.60 was deferred. To reverse the downward spiral of academic research facility conditions, full funding of the Academic Research Facilities Modernization provisions of the National Science Foundation Authorization Act of 1988 must be made.

TRAINING AMERICA'S SCIENTIFIC AND ENGINEERING WORK FORCE

America's ability to expand its research and development effort is dependent upon the availability of skilled technical workers to carry out the necessary experiments. A well trained science and engineering work force is essential for America to become more competitive. It is the "human infrastructure" upon which growth in U.S. research and development must depend.

Today, 1,300 to 1,800 engineering faculty positions at United States' colleges and universities are vacant. Fewer positions exist than are needed to maintain and restore the quality of graduate engineering programs. The combined shortfall exceeds 18 percent of the necessary engineering faculty.

In addition to the shortage of faculty, engineering schools are unable to attract sufficient numbers of qualified United States students into their graduate programs. A decreasing percentage of United States students are interested in pursuing careers in science and engineering. Of the 4 million high school sophomores in 1977, only 206,000 had received Bachelor of Science degrees in natural sciences and engineering by 1984. Only 46,000 of those had received Masters of Sciences degrees in natural sciences and engineering in 1986. Of those 46,000, it is anticipated that only 9,700, or less than one-quarter of 1 percent of the 1977 high school sophomore class, will receive doctorates in natural sciences and engineering in 1992. Nine thousand seven hundred new engineering doctorates are not enough to meet our research and development needs.

The downward trend continues. In 1982, over 12 percent of entering college freshmen showed an interest in majoring in engineering, but the percentage declined by one-quarter, to a little over 9 percent, in 1987.

Fortunately, the shortage of qualified United States' students has been offset to some degree by the increasing number of foreign students enrolling in United States' universities and pursuing studies in science and engineering. Foreign students represent approximately 40 percent of the enrollment in United States' engineering graduate schools and they receive more than half of the United States' doctorates in engineering. Without foreign student participation in these programs, the shortage of qualified engineering personnel in both industry and United States' universities would be devastating. But many of these foreign students return home to their own countries and the

United States does not get the long-term benefit of their training.

The National Science Foundation has found that approximately 60,000 of today's math and science teachers in America's secondary schools are not fully qualified and that, by 1995, the United States will need an estimated 300,000 additional secondary school math and science teachers. With a decreasing population of students entering science programs, the United States will have a difficult time meeting this need. Ultimately, in light of the potentially decreasing number of college age students in the United States and the declining percentage of those students choosing to pursue careers in science and engineering, the shortage of qualified scientists and engineers may reach 500,000 by the year 2010.

The shortage of qualified scientists and engineers is not a problem of the future, it is a problem today. Between 1969 and 1982 the rate at which the United States residents patented their discoveries abroad decreased by 50 percent. At the same time, foreign applicants increased their share of United States patents from approximately 35 percent in 1975 to 46 percent in 1987. Most of this growth is accounted for by the increased number of Japanese patents. Without sufficient numbers of scientists and engineers to conduct research, it is a certainty that the United States' share of world-wide patents will continue to decline.

To reverse the trend, the Federal government should:

1. Bolster elementary and secondary science and mathmatics education by supporting pre-school programs such as Head Start, funding programs to upgrade the skills of science and math teachers, and creating incentives for talented science and engineering students to become teachers.

2. Substantially increase support for undergraduate and graduate education in science and engineering by expanding the funding of basic university research and reversing the loan/grant imbalance in undergraduate and graduate education.

3. Expand programs to raise the percentage of women and minorities in our scientific and technical work force by establishing graduate fellowship and research internship programs directed towards minorities and women, and providing matching grants to develop and replicate successful recruitment and retention programs for undergraduate and graduate women and minority students.

4. Support or stimulate career-long continuing education programs by providing tax incentives for industry to offer continuing education, and re-enacting and making permanent Section 127, particularly to include graduate education.

5. Foster communication and collaboration among government, industrial, and educational partners by reviewing and updating Federal programs that support training and retraining the scientific and technical work force; convening a national conference of state level forums and institutions that are working to enhance the skills of their scientific and technical work force; including as part of major Federal scientific or technical projects the assessment of its work force requirements and direct investment in training the needed personnel for those projects; and ensuring that immigration laws allow foreign nationals with needed skills to remain in the United States.

CONCLUSION

Mr. Chairman and Committee members, I cannot over-emphasize the need for a predictable and stable research and development policy, both with respect to Federal income taxation and governmental expenditures. A permanent solution to the 861-8 Regulations problem and a permanent R&D credit, as well as sustained funding for the Academic Research Facilities Modernization program and increased support for training the American scientific and engineering work force must be a centerpiece in our nation's research and development policy. The rewards from stimulating research and development are clear. Even in times of severe budget pressures, it is imperative for the government to find a means to support research and technology. By investing in research and development today, we will create a healthier, more vibrant, more competitive American economy.

* * * * *

Mr. Hayes. Thank you. There are a couple of things, especially in light of the last panel, that I would like to inquire about without keeping you here all afternoon. It occurs to me that there is perhaps less of a difference between Mr. Lawrence and Dr. Eisner as the concise statements would indicate.

Let me give this illustration: There was a major banking institution with which I'm familiar as a former regulator, that had the largest R&D budget in my state. It did so because of tax planning considerations. I suggest in accordance with what Dr. Eisner mentioned earlier, that the use of automatic financial service terminals would have come about anyway as a response to the marketplace.

Yet there is no doubt you could not have stopped the automatic teller machines from being established. And yet all of this was under R&D, primarily because at that time there was tax considerations that guided them.

I represented a law firm not dissimilar to Mr. Eizenstat's. My role was to look at the code with the goal of finding opportunities to serve our clients by giving them the best benefit of our advice on ways to avoid paying higher taxes. That's our motivation.

And yet, with the example given, I'm certain that the intent of R&D, the motivation, did not result in any bank activity, nor was it what we were attempting to inspire, legislatively, by the creation of those code provisions.

Yet, after having said this, I assure you, I am a strong proponent of the R&D tax credit because we have got to get to where we need to go. It is clear. It is undeniable statistically that the rest of the world is using research and development in civilian areas, though we still need it in military development, that outstrip ours, and that they are gaining an economic benefit from doing so that is visible by any objective person.

Would it not perhaps be correct to say, that in a blend of your statement, Dr. Eisner, with Mr. Lawrence's, what we really are asking is to more pinpoint our R&D legislation so as to reach the areas that need encouragement, and to do our best to avoid those provisions that can lead to subsequent abuse, or to incentives based solely upon paying or not paying taxes, rather than guidance toward research and development.

One of the suggestions contained in your statement is a base average for different industries. In light of this, can't we improve our legislative goals, and accomplish what Mr. Lawrence is saying, and at the same time, avoid some of what Dr. Eisner is saying? I'll address that to both of you.

Dr. Eisner. Well, there are ways to improve the current proposals—I have them outlined briefly in my statement—to make them somewhat more effective. The basic problem is that everything economists say has an opportunity clause, and of course, everybody would like to have more of everything. Just within the field of R&D itself, of research, the question is where is the role for Government? Where can the Government—should it encourage things that would not otherwise be done because it is not in the interests of private companies to do them?

The difficulty is that everybody would like to have his taxes down. The Tax Reform Act of 1986, I think, wisely moved in the way of eliminating some of these special codes, including in particular the investment tax credit where many of the same arguments were made, I think, even all the more fallaciously. The notion we have in a competitive free enterprise capitalistic economy is that business should do what is profitable for it. If you cannot show that it would not do something profitable for it—if you can show it won't do something profitable for it, you're in a rather queer indictment of the entire system. If it's profitable by itself, the tax advantage is just extra gravy. If it's not profitable by itself, then you have to make sure that the tax advantage of getting them to do it is really in the interests of society.

I would say that applies where we have what are know as public goods, where we have things where the benefits to the rest of the country exceed the benefits to that company, so that it pays to do it. That is true in regard to education, the basic preparation of scientists.

Dr. **Lawrence**. Well, I would pick up where Dr. Eisner left off. I would agree exactly with what he said, and I would argue that in fact, it has been certainly well established that there are public good aspects to commercial research and development. The spillovers that result, and I'm stressing here commercial, that the spillovers that result from commercial R&D result in a return to society which is two to three times as large as the return to the firm itself.

This is on the basis of studies which have looked, let me stress again, basic research and development expenditures. So I do believe that this is an area which meets the appropriate criteria, which is to say, there are social benefits that far exceed those that are available to the private decision makers themselves.

Let me say secondly, that we're trying to design something and it is a very tough problem. Because it's what my late colleague Arthur Oaken once called the "leaky bucket." What we're trying to do is create an incentive at the margin and design it in such a way that we will not reward people for doing something they would have done anyway. We want to get them to add that extra dollar without wasting money on all the intra-marginal dollars. That's a tough design problem. I don't think there is a simple, single answer.

Now, the R&D tax credit, the original one, was one effort at trying to do that. The idea of the base was indeed to try to get away from spending which would have been carried out anyway. As Professor Eisner pointed out, among others, unfortunately in that design, although it did provide some incentive, it was not as large an incentive as you could have by making the base independent of the individual's decision.

So we have now moved to a second formula. Now, I personally think it is an empirical matter as to whether we should go to the industry level or whether we should go to some other basis. I think using the GNP is a reasonable base. But I would not be wedded to that. If you could show me that there is a better way to do it, I think we could do it that way. I think by and large, it is important when we make this permanent, and I think the provisions of the bill do provide it, that we look again in five years, say, as to how that base is doing.

Is it totally unrealistic? Has spending far exceeded that base or is it falling behind it? In some sense it's going to be crude because we're trying to do something that's very difficult to do. I think that the GNP is a reasonable number, but I don't think there has to be a single obvious alternative that dominates.

Mr. **Eizenstat**. Mr. Chairman, may I?

Mr. **Hayes**. I was just about to say, if either of you gentlemen would care to jump in—

Mr. **Eizenstat**. Yes, thank you. First, it is important to recognize when this was originally designed back in 1981 it was designed as an incremental credit. You don't get the first nickel of credit unless you exceed the base.

The second point is that in response to the critique of Mr. Eisner and others, the Treasury Department, and I worked with them on and off for a good while, came up with this fixed base concept precisely so that we would have the full value at the margin of the 20 percent credit.

The third point is that, of course private firms did research and development before there was an R&D credit and of course they would do it if there were no R&D credit. What we are trying to do, and what I believe we've conclusively demonstrated by Dr. Eisner's studies and others, is that because there is a gap between what the market encourages companies to do, with all the risks inherent, with all the long lead times for projects, with all the failures that occur from R&D, and what is in society's interest to have them do, that you can encourage more R&D than the market would otherwise encourage by this incentive.

That's what we're trying to do and that's what, in fact, the R&D credit has done. We think that with the new base period it will be an even better incentive.

Mr. **Hayes**. Dr. Womack, I believe, if I am not a victim of my own handwriting, that you had made one of the references to antitrust in a portion of the conversation today. I would like to carry that through in light of the previous panel.

It seems from what we hear on this committee and almost universally, from almost any source, that we're dealing with competitors who, from whatever structure, in the interrelationship of their government and business, and universities, even, can cross through some of our bounds of antitrust relationships, and are able to put together larger joint efforts. So there is a pressure always to say "let us be more cooperative at that level."

That's a legitimate concern and certainly one responsive to a competitor who can do things you can't do. On the other hand, as someone who is elected by very small business people, and individual consumers, let's take Dr. Caulder's comment earlier about his small company.

So if we're sitting there talking about how to facilitate IBM and Apple to do a worthwhile project, and if the reference made by Bill Poulos of 9,000 similar companies—we're suddenly going to be at that crossroads where, on the one hand, attempting to do a better governmental service, we have 8,995 other people locked outside of the door, saying "wait a minute, granted we're not your size, but we're in that business, and suddenly we don't care to compete with John Rockefeller all over again."

How do we balance that interest and how do we select those areas of participation where we cross that line, and at the same time, how do we preserve Dr. Caulder's company from unfair competition when these selections are made?

Finally, how do we avoid doing what we just said didn't look too good for the Air Force in its design specifications. By designing an entity that shuts the door on others, isn't that the equivalent of making the request for a design that shuts the door on others? How do we balance those things?

Dr. WOMACK. I wish I had both the wisdom and the experience to answer that question in full.

Obviously, none of these issues is black and white. All I was attempting to do was point out that at the time, as in so much of our business culture in the United States, we had a view, perhaps that lasted even as late as the mid-1970s, that we were a law unto ourselves, that the entire world ended at our borders on the Atlantic and Pacific and with Canada and Mexico, since our market was so large, and since our productive capacity was so large, and since we were good at everything. And we needed to speak primarily in order to protect those small companies—a principle, by the way, which I thoroughly advocate—to protect those small companies and to avoid collusion in pricing, to avoid the kinds of things that I think we would all deplore, to create laws within the United States, antitrust laws in the United States, some of which have survived, and in many of which deserve to survive.

All I was attempting to point out is that the economy now includes a much larger playing field and a much larger number of players, some of whom are not subject to the same restrictions; and furthermore, because of the larger number of players, some of the reasons for the original restrictions may no longer be valid. It's not a subject which I'm prepared to answer in detail. I would certainly agree with you that it's a difficult subject. It requires some balance.

I did want to point out that it is very encouraging to see some of the barriers, which might 10 or 15 years ago have made it very difficult, or at least would have made me very hesitant, to sit down and talk with counterpart R&D managers in my industry about the possibility of joint programs in procompetitive development, to see those barriers relaxed by action on the part of the Congress and the Administration.

And I think it's useful with more time and more effort to examine the other phases of the commercial development process and see if pushing, or removing or limiting, those kinds of barriers in later phases in the near commercial phases and perhaps even in the production phase of the process, with restrictions, is not desirable.

R&D consortia, which would enable us to pool what we've already spoken of as limited resources around the table, I think are going to have to be done in this country if we're going to work within the box of the availability of those resources.

Mr. HAYES. If any of you would care to jump in that's fine. I would also like to add the concept before I ask anyone to jump in, of the same thing, the university- corporate cooperation. I had an opportunity only a few months ago, through being in Japan for a short length of time to be able to see first-hand that you cannot tell the personnel that are corporate from the graduate students. They are identical, they intermingle and they are a cohesive work force that does precisely what you said, and that is accomplish a conversion from beginning to end much more rapidly than we can.

The one problem I see, while at the same time suggesting that is effective and efficient, is there is not an equal competition among major universities in the case I used of Japan, where Government adds itself as a third player in that university-corporate structure, and in effect details roles of, not the university as a community, as a generic term, but The University upon which the facility will be located.

The equivalent of that would be to ask this panel with its rather broad background when it is in full Committee of Science and Tech, to take Johns Hopkins and Cal Tech and MIT and the University of Michigan, and add two or three more, to the exclusion of the rest of the community and say, they are awfully well prepared for this project. I know it's the same box, but I would be most interested in any of your observations, because it's the one in which we find ourselves. Certainly, the goal is enviable and certainly the structure of our competitor requires a reaction.

But the reaction has to be something, in my opinion, different from emulating it. It's got to be a variation of it. What's the best way to create that variation without giving up the uniqueness of our society that allows small businesses to create themselves, and allows universities with individual research projects to go forward?

Mr. Womack. Let me just seize on the last remark you made that the emulating our competitor is not the easy solution that it may appear. Obviously, he has strengths which make some of those things work for him which are born of the culture in which he lives.

We have a culture which values independent action, personal innovation, and competition. It's the strengths of that culture that I feel we need to reinvigorate in order to solve the problem we've been discussing.

It's on that basis that I am suggesting, certainly not suggesting that the Government get into the business of picking winners and losers, but rather to enrich the resources and the tools which enable that structure to function well, and which are now in somewhat sad repair.

The fact is that a commercial enterprise in the simplest form requires four things. It requires a customer, it requires an idea for a product, it requires skilled people and it requires production tools. Three of those four things are in questionable repair in the United States. The only thing that nobody has challenged is that we're very good at being customers, we're very good at being consumers.

We can stand to look carefully at the idea production process, at the process of producing skilled people, and at the process of making available the capital, that is the savings, which go to form the production tool. If we do that, and if we do it effectively, I think our culture will do the rest.

Mr. Eizenstat. There are, Mr. Chairman, at least two activities which I think go to your point. One is that the National Science Foundation has been creating, and I certainly think they've done a good job, the Centers of Excellence which are bringing together businesses, small and large, and universities. I think that needs to be expanded.

Second, as I indicated, the university basic research credit is designed specifically to encourage corporations to contract out their basic research to universities and non-profit institutes, so that that kind of collaborative effort is encouraged.

It's too early to say what impact that has had. It was only passed in the 1986 Act, but anecdotally, at least, our companies are very encouraged by how it's working.

Dr. **Eisner**. I would just pick up one of Dr. Womack's points. I think again, industry will lack skilled persons, skilled people, and that's the one place you can't expect industry to help itself. Because we're not a slave economy, it doesn't pay an individual company to adequately educate and train people, because they can't keep those people, they can go elsewhere.

It's a basic responsibility of government and society to invest in human capital. That is where I believe this Committee should look for ways to proceed, and to proceed effectively.

Mr. **Hayes**. Thank you. I want to thank all of you. I am going to roughly adhere to the time because this is one of those occasions where I think there is some pressure for this room.

So we're a little bound today by constraints that we won't always be bound by. I do want to add a few things to this record, however, before closing, the submissions that were made, and I will just state the record will be open.

Also, what we'll do, if there are any additional materials that not only any of our panel members but other interested parties would wish to submit, then the record will be open for that purpose.

I thank all of you for coming, and as I said earlier, one thing I have learned in a short time is that more people read what you submit that I suspect you believe read it, and it has a broader impact than you might think it has.

As illustration of that I will assure you that the present amendments involving Section 89 of the Internal Revenue Code came about almost entirely because of staff reading letters, comments and documents from accountants and small businessmen across the country that gave graphic examples of their opinion of the impracticability of that legislation.

Likewise, much the good we can do is in the same fashion as your specific examples and the only thing I would further encourage that we are always in short supply of, is alternatives.

While we don't expect them to be perfect, and while anyone who offers any suggestion opens themselves to criticisms from their colleagues, it's still the best source of information for us, to see people who are intimately dealing with issues to make suggestions, while not perfect, are improvements. I would certainly urge and encourage you to please continue doing so. From that criticism alone comes a constructiveness that we can't duplicate elsewhere.

Thank all of you for being a part of this hearing. I certainly appreciate your coming and I can only tell you that this is an issue that is evidencing itself in such magnitude that our country needs your continued input to improve our past and hopefully to better plan our future.

Thank you very much.

[Whereupon, at 1:12 p.m., the subcommittee was adjourned, to reconvene at the call of the Chair.]

APPENDIX

KEY TECHNOLOGIES FOR THE

1990s An Overview

Aerospace Industries Association of America, Inc.

> ***"America's competitiveness in world markets is critical to maintaining and expanding our standard of living and the national security. I have established a national goal of assuring American competitive preeminence into the 21st century. Achieving that goal is the responsibility of all Americans."***

President Ronald Reagan
State of the Union Address
January 27, 1987

KEY TECHNOLOGIES FOR THE 1990s

An Industry Study of High-Leverage, Enabling Aerospace Technologies and Roadmaps To Attain Them

A Report of the Aerospace Technical Council of AIA

NOVEMBER 1987

AEROSPACE INDUSTRIES ASSOCIATION OF AMERICA, INC.
1250 EYE STREET N.W. • WASHINGTON, D.C. 20005

AIA AEROSPACE TECHNICAL COUNCIL STUDY GROUP

AIA represents the major U.S. aerospace companies engaged in the research, development and manufacture of aircraft, missiles and space systems and related propulsion, guidance, control and other equipment. The association functions on national and international levels.

The Aerospace Technical Council is the industry's senior technical body and is chartered to focus on the development of high-technology systems.

Chairman

John M. Swihart
Corporate Vice President
The Boeing Company

Key Technologies Steering Group

Dr. James R. Burnett
Executive Vice President and General Manager
Space and Defense Sector, TRW, Inc.

Robert L. Gaffel
Senior Vice President, Research and Engineering
Rockwell International Corporation

C. Ronald Lowry
Vice President, Research and Technology
Aerospace Industries Association

Lawrence M. Mead, Jr.
Special Technical Assistant to the President
Grumman Corporation

Dr. David Passeri
Vice President, Engineering
Bendix Aerospace Sector
Allied-Signal Aerospace Company

Technology Roadmap Study Leaders

ROADMAP COORDINATOR

Richard H. Hartke
Director, Technology Programs
Aerospace Industries Association

COMPOSITE MATERIALS

Dr. Felix W. Fenter
President, Missiles Division
The LTV Corporation

VERY LARGE SCALE INTEGRATED CIRCUITS

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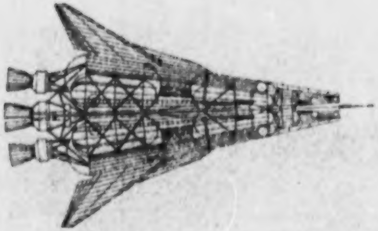

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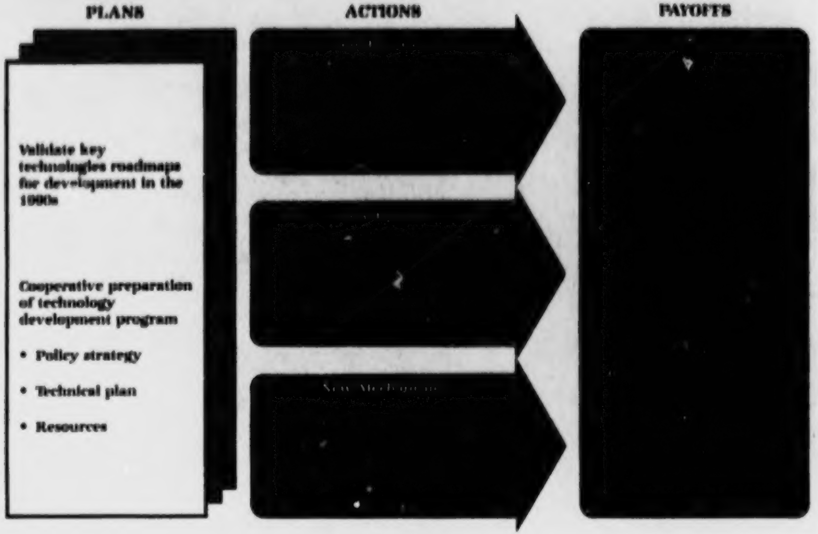
U.S. AEROSPACE COMPETITIVENESS INITIATIVE


PLANS
ACTIONS
PAYOFFS
New Mechanism

Validate key technologies roadmaps for development in the 1990s

Cooperative preparation of technology development program

- **Policy strategy**
- **Technical plan**
- **Resources**

INTRODUCTION

The U.S. aerospace industry is in danger of losing its competitive position in world markets and its superiority in military capability. Although the industry has consistently maintained a substantial positive trade balance, aerospace imports are increasing rapidly and U.S. aerospace competitiveness is eroding.

Foreign competitors have worked diligently to upgrade their technology and the capabilities of their products now equal or exceed ours in several important fields.

For the past five years, the AIA Aerospace Technical Council has been studying the developmental status of aerospace technologies. Of the over 100 technologies reviewed, eight key technologies were identified as needing immediate and special attention based on selection criteria of highest leverage, potential payoff and broadest application.

In the aerospace industry, technology development is the key to international competitiveness.

This report proposes a national strategy to improve the U.S. competitive position in the global trade arena by creating a new national effort—one which cooperatively harnesses industry, government and academia together on the focused development of key enabling technologies to regain the U.S. aerospace industry's world leadership.

The overall intent of this report is to:

1. ***Present an overview of the eight technologies***
2. ***Encourage federal endorsement of a long-term cooperative research and development effort including the participation of government, industry and academia***
3. ***Provide a basis for a truly national effort enhancing the technology development process***

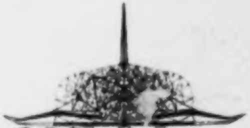
COMPOSITE MATERIALS

Advanced composites make up a family of lightweight aerospace structural materials that offer significant weight savings, as well as structural integrity, in comparison to current metal alloys. Their use is predicted to result in more fuel-efficient aircraft, lighter missile and spacecraft structure, reduced manufacturing and labor costs and a more innovative approach to aerospace design. Since emerging aerospace systems are in need of such benefits, advanced composites technology can have a great effect on many programs of national interest.

At present, a number of application barriers still exist, even though advanced composites have been studied for some time. Confidence in this relatively untested technology is not yet strong, and many costs still remain prohibitive. However, advanced composites exhibit such an excellent strength-to-weight ratio that the potential future market is quite large. This factor alone is enough to encourage significant cost reduction through competition between suppliers.

Aspects of this technology, such as lower structural weight and greater component heat resistance, make advanced composites a required area of development for future aerospace applications, such as high-speed aircraft and advanced propulsion systems. Currently, development is concentrating on improving the performance of the basic materials and identifying cost-effective applications. Due to the complexities of composite materials, such as their directional properties, their low ductility and fiber/matrix interface problems, there is a need for advanced automated design and manufacturing techniques, as well as more highly skilled engineers who are familiar with the developmental problems of composites technology.

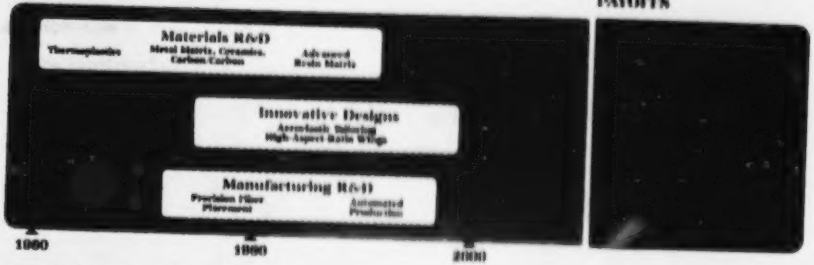
Encouragement of this R&D effort would help the U.S. composites industry maintain its lead. Future program requirements demand that immediate attention should be given to the fabrication of materials exhibiting even greater toughness, utility and resistance to higher temperature. With a sufficient effort, a 20% to 50% reduction in production costs for most aerospace structures could be realized before the year 2000.



COMPOSITE MATERIALS

ACTIVITIES

PAYOFFS


Materials R&D
Thermoplastics
Metal Matrix, Ceramics, Carbon-Carbon
Advanced Resin Matrix
Innovative Designs
Aeroelastic Tailoring
High Aspect Ratio Wings
Manufacturing R&D
Precision Fiber Placement
Automated Production
1980
1990
2000

ADVANCEMENT INHIBITORS

- Materials and processes are still evolving
- Questions of long-term durability
- Raw material and processing costs are high
- More skilled engineering resources are needed

8

REQUIRED DEVELOPMENT

- High-temperature materials
- Refined structural analysis methods
- Unified technical data base
- Improved environmental durability
- Innovative, low-cost manufacturing methods
- Simplified repair methods
- Advanced automated design techniques

COMPOSITE MATERIALS

RECOMMENDATIONS

- Institute a major national program to accelerate development of a broad technology base with active government, industry and university support
- Demonstrate maintainability and cost-effectiveness of advanced composites
- Pursue new and innovative material forms and processes to exploit potential of advanced composites
- Continue development of advanced automated design and analysis methods for effective and efficient fulfillment of system requirements

MAJOR BENEFITS

The application of advanced composite materials represents the potential for major improvements in the weight and integrity of aerospace structures

Benefits	Applications			
	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	●	●	●	●
[illegible]	●	●		
[illegible]	●	●		●
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[illegible]	●	●	●	

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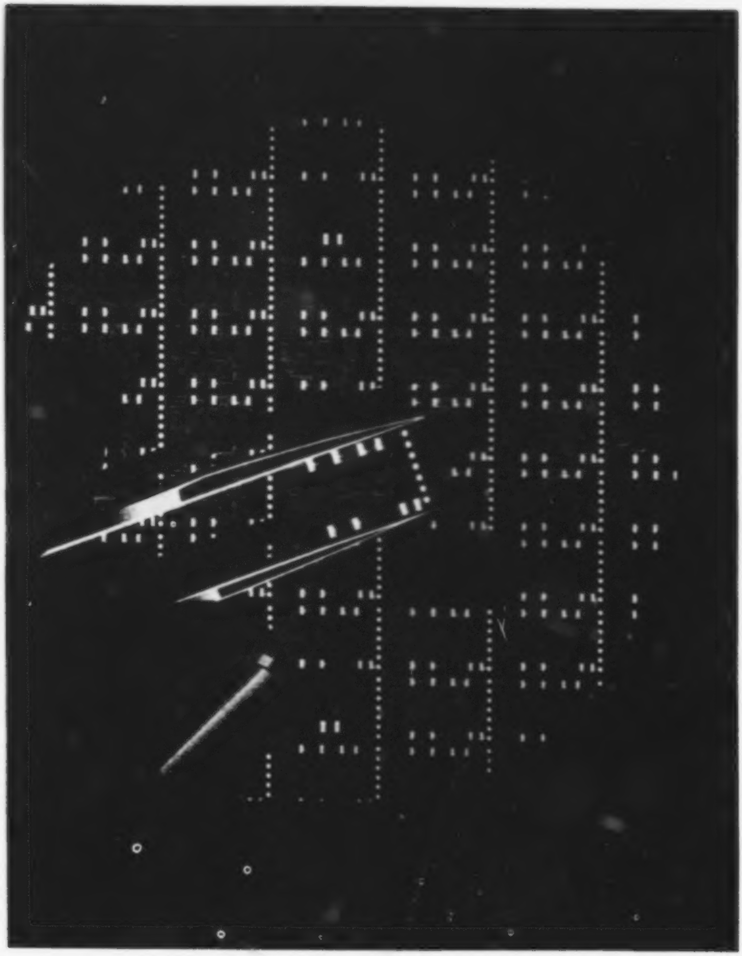


VERY LARGE SCALE INTEGRATED (VLSI) CIRCUITS

The revolutionary advances made in aerospace electronics have been driven by the advances in integrated circuits. The staggering amount of expertise focused on electronics microminiaturization has provided very large scale integrated (VLSI) circuits. By the turn of the century, the number of transistors per chip will reach into the tens of millions. Additionally, new materials are emerging, particularly gallium arsenide (GaAs), that have the promise to further increase the electronic speed on a chip by a factor of three or more. Recently announced achievements in superconductivity might provide further advances in VLSI circuit performance.

Such compact circuitry will provide computers with an even greater computational capability, and yet they will be smaller, more reliable and easier to maintain. They will give unprecedented performance in aerospace and many other fields, providing the "brains" for aircraft, satellites and weapons. Additionally, they will play a pivotal role in the development of other newly emerging fields, such as artificial intelligence, and will be applied broadly throughout the civil economy.

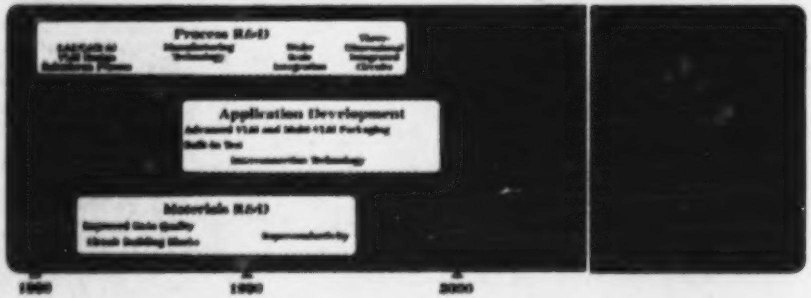
Although the U.S. pioneered integrated circuits, foreign manufacturers now dominate production of commercial semiconductor devices and have rapidly implemented new technology, including VLSI. The DOD VHSIC and MIMIC programs are promoting significant advances in U.S. capability, and a recent industry/government program, SEMATECH, is helping to ensure domestic manufacturing sources.

It is essential that these initiatives be sustained. Major new emphasis is needed so we can achieve improved design simulation; submicron scale device fabrication; enhanced aerospace attributes such as ruggedness, testability and radiation hardness; advanced semiconductor materials; and interconnecting and packaging.

These challenges can be met by key, focused programs designed to cooperatively advance these vital areas. Without such initiatives, the U.S. may not achieve its essential technological goals and leadership will continue to remain with foreign interests.

VERY LARGE SCALE INTEGRATED (VLSI) CIRCUITS

ACTIVITIES **PAYOFFS**


Process R&D
[illegible]
Manufacturing Technology
Wafer Scale Integration
Three-Dimensional Integrated Circuits
Application Development
Advanced VLSI and Multi-VLSI Packaging
Built-In Test
Interconnection Technology
Materials R&D
Improved GaAs Quality
Circuit Building Blocks
Superconductivity
1980
1990
2000

ADVANCEMENT INHIBITORS

- Aggressive foreign investment
- Insufficient risk-sharing partnership between industry and government
- Neglect of some technology areas limits application
- Government specifications inhibit commercial advances and applications

REQUIRED DEVELOPMENT

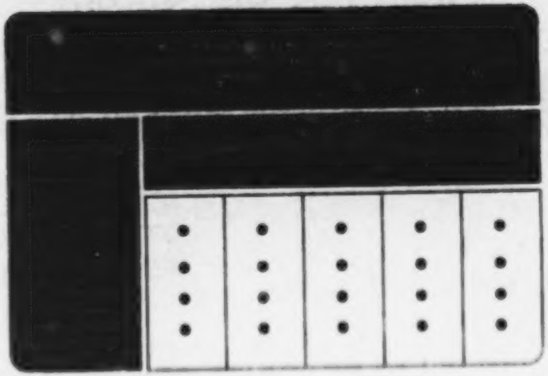
- Continued advances in submicron process technology
- Major, rapid advances in manufacturing processes and equipment
- Advances in specific areas: integrated circuit design, packaging, interconnection, printed wiring boards, built-in test, GaAs and other advanced materials

VERY LARGE SCALE INTEGRATED (VLSI) CIRCUITS

RECOMMENDATIONS

- Major new emphasis on submicron process development
- Increased emphasis on new, improved materials and processes such as gallium arsenide and superconductivity
- Focused programs on:
  - VLSI packaging
  - VLSI built-in test
  - GaAs materials, design and packaging
  - Interconnections

MAJOR BENEFITS



SOFTWARE DEVELOPMENT

Computer systems are currently generating more data than we can process. Without significant gains in software development, the sheer volume of information and the increasing complexity of computer systems will become liabilities rather than assets. Therefore software, the language and logic of computer operation, is rapidly becoming the key to the automated world of the 21st century. The ultimate usefulness of such future U.S. projects as the space station and strategic defense systems will be crucially dependent on our advanced software capabilities. Further, the success of automated factories, air traffic control networks, banking systems and numerous other complex computer applications is dependent on software for control and support. A vigorous, sustained software research effort is essential to meet the requirements of the future.

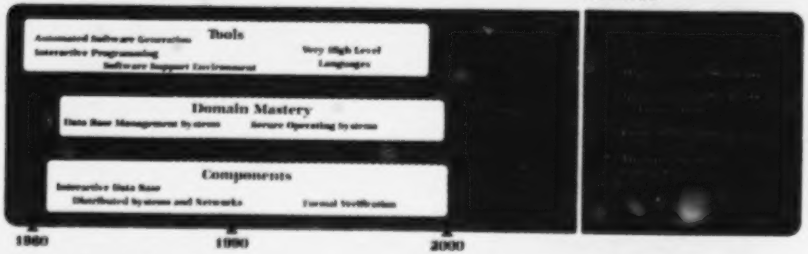
Because of their interrelatedness and versatility, some software technology areas offer particularly high payoffs. These areas include support environments, very high level languages and computer-aided software requirements and design capabilities. The recent Ada initiative has provided a foundation for making progress in these areas. Other important software technologies, in terms of their leverage on aerospace capabilities, are data base management systems, multilevel security and artificial intelligence (AI). Recent experience with AI applications has indicated that major payoffs require combinations of AI and conventional software capabilities. This implies that greater investments in conventional software technologies are needed to realize fully the payoffs from investments in AI technology.

Development of advanced software technology is currently limited by the level of funding, the degree of formal understanding, the lack of focused research efforts and the availability of key personnel. While the United States is in the forefront of this technology, major foreign consortiums already exist, and European countries are currently leading the United States in certain areas of software development. An R&D thrust centered on advanced software could lead to an order-of-magnitude increase in the productivity of computer systems and an equal decrease in error rates before the end of the century.

SOFTWARE DEVELOPMENT

ACTIVITIES

PAYOFFS


Tools
Automated Software Generation
Interactive Programming
Software Support Environment
Very High Level Languages
Domain Mastery
Data Base Management Systems
Secure Operating Systems
Components
Interactive Data Base
Distributed Systems and Networks
Formal Verification
1980
1990
2000

ADVANCEMENT INHIBITORS

- Lack of focused developmental efforts to accelerate advances in software support environments and very high level languages
- Lack of personnel skilled in various technology development areas
- Interoperability between AI and conventional software capabilities
- Ineffective cooperation between academia and industry
- DOD software acquisition practices

REQUIRED DEVELOPMENT

- Software for parallel and distributed processors
- Software support environments
- Efficient formal software capabilities
- Automated software generation capabilities
- Formal principles for multilevel security, data base interfacing and proof of correctness
- Aerospace-oriented very high level languages
- Hybrid AI conventional software systems

SOFTWARE DEVELOPMENT

RECOMMENDATIONS

- Modernize software acquisition practices through joint government/industry development
- Reinforce Software Engineering Institute's role as technology transfer agent
- Create incentives for academia and industry to work cooperatively on different aspects of the same problem or idea
- Expand and reorient software/AI R&D program
- Take greater advantage of available software technology

MAJOR BENEFITS

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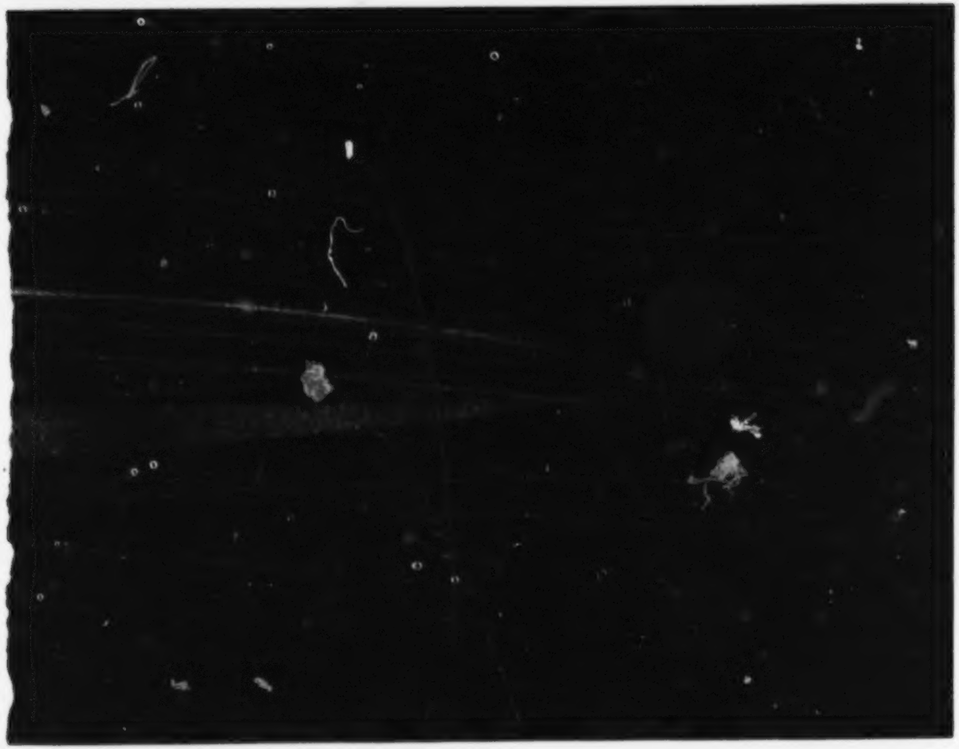


PROPULSION SYSTEMS

Within 20 years, advancements in propulsion technology could result in the design of subsonic transports requiring 30% less fuel and fighter aircraft with sustained Mach 3+ capability. New propulsion concept developments are critical to future designs such as an advanced supersonic civil transport and hypersonic or transatmospheric vehicles. For space flight, improved durability and performance capability of rocket engines could enable an order-of-magnitude cost reduction for placing payloads into low earth orbit. Advanced technology will also enable more versatile and cost-effective missile systems. Concepts already exist that would enable many of the cited advancements, but capability is yet to be proven.

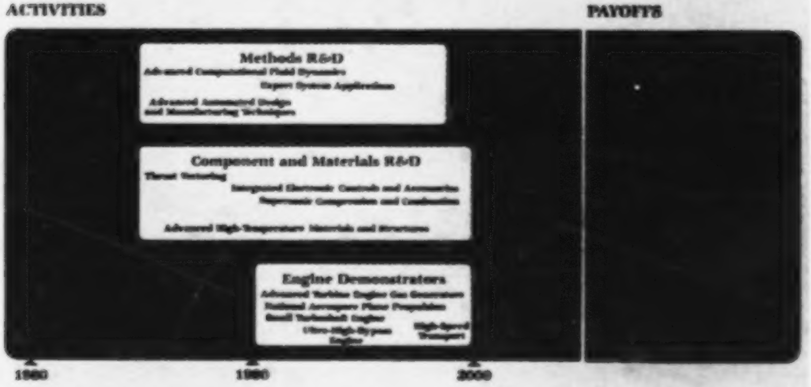
Current propulsion programs include the National Aerospace Plane (NASP), the Advanced Launch System (ALS) and the Integrated High Performance Turbine Engine Technology (IHPTET) programs. The AIA agrees with the goals of these programs and views their continuation over the next decade as essential. However, even though these programs will provide substantial benefit to aircraft propulsion requirements, they will not provide answers in all key areas.

For example, a dedicated initiative is needed for further development of gas turbine power plants, the mainstays of commercial and military aircraft, and to explore the potential of much higher flight speeds. Rocket engines also need accelerated development to reestablish the U.S. position of preeminence in space. Current and planned space propulsion systems are based on 20-year-old technology. A sustained national commitment is required to investigate and demonstrate new designs that will benefit U.S. missions.

Advances forecast for both airbreathing and rocket engine types make it clear that a complete reevaluation of engine architecture, fuels and materials must take place. The schedule of progress in propulsion technology development may hinge on the ability to fabricate complex propulsion systems from high-temperature composite materials. This is one more indication of the criticality of key technologies and the benefits to be gained by focusing on their development.

PROPULSION SYSTEMS

Airbreathing Engines



ACTIVITIES

PAYOFFS

Methods R&D

Advanced Computational Fluid Dynamics

Expert System Applications

Advanced Automated Design and Manufacturing Techniques

Component and Materials R&D

Thrust Vectoring

Integrated Electronic Controls and Accessories

Supersonic Compression and Combustion

Advanced High-Temperature Materials and Structures

Engine Demonstrators

Advanced Turbine Engine Gas Generators

National Aerospace Plane Propulsion

Small Turboshaft Engine

Ultra-High-Bypass Engine

High-Speed Transport

1960

1980

2000

ADVANCEMENT INHIBITORS

- Absence of national plan for advanced subsonic and supersonic commercial aircraft propulsion development
- Unavailability of advanced high-temperature materials
- Insufficient development funds
- Lack of skilled engineering resources

REQUIRED DEVELOPMENT

- Turbomachinery
- Combustors/augmentors
- Inlets and exhaust systems
- Controls, accessories and mechanical systems
- Advanced automated methods

PROPULSION SYSTEMS

Airbreathing Engines

RECOMMENDATIONS

- Continue planned technology base programs for IHPTET, NASP and high-speed commercial transport (HSCT)
- Pursue new and innovative material forms and processes in all temperature ranges
- Develop knowledge-based computer systems for propulsion applications
- Exploit technology demonstrator vehicles with challenging systems objective as a key development strategy
- Develop advanced automated design, manufacturing, test and analysis methods

MAJOR BENEFITS

New propulsion technology developments will provide major gains in propulsion systems capability for a wide range of potential applications

	Applications		
	Aircraft	Missiles	NASP and HSCT
[illegible]	●	●	
[illegible]	●	●	●
[illegible]	●	●	●
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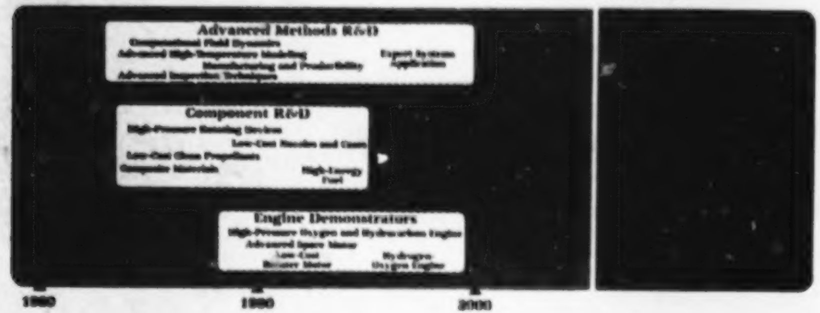
PROPULSION SYSTEMS

Rocket Engines

ACTIVITIES

PAYOFFS



Advanced Methods R&D

Computational Fluid Dynamics

Advanced High-Temperature Modeling

Manufacturing and Producibility

Advanced Inspection Techniques

Expert Systems Application

Component R&D

High-Pressure Rotating Devices

Low-Cost Nozzles and Cases

Low-Cost Clean Propellants

Composite Materials

High-Energy Fuel

Engine Demonstrators

High-Pressure Oxygen and Hydrocarbon Engine

Advanced Space Motor

Low-Cost Booster Motor

Hydrogen Oxygen Engine

ADVANCEMENT INHIBITORS

- Perceived as technically mature
- Inadequate development funds
- Growing foreign competition
- No longer a glamorous technology
- Shortage of skilled engineers
- Lack of sustained support and specific, long-range U.S space goals
- Inadequate test facilities

REQUIRED DEVELOPMENT

- Advanced automated methods
- Cost-driven design methods
- Improved materials
- Improved manufacturing methods
- Nondestructive testing techniques
- Technology demonstrators

PROPULSION SYSTEMS

Rocket Engines

RECOMMENDATIONS

- Reestablish a national commitment to foster the advances necessary to maintain technological excellence
- Expand national propulsion technology programs to advance analytical and computational methods
- Investigate new materials and fuels, methods of manufacture and inspection techniques
- Expand health monitoring and control systems to enhance low-cost operations
- Investigate combustion phenomena and advanced heat-transfer techniques
- Test engine demonstrators to verify technology gains
- Develop advanced automated design, manufacturing, test and analysis methods

MAJOR BENEFITS

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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ADVANCED SENSORS

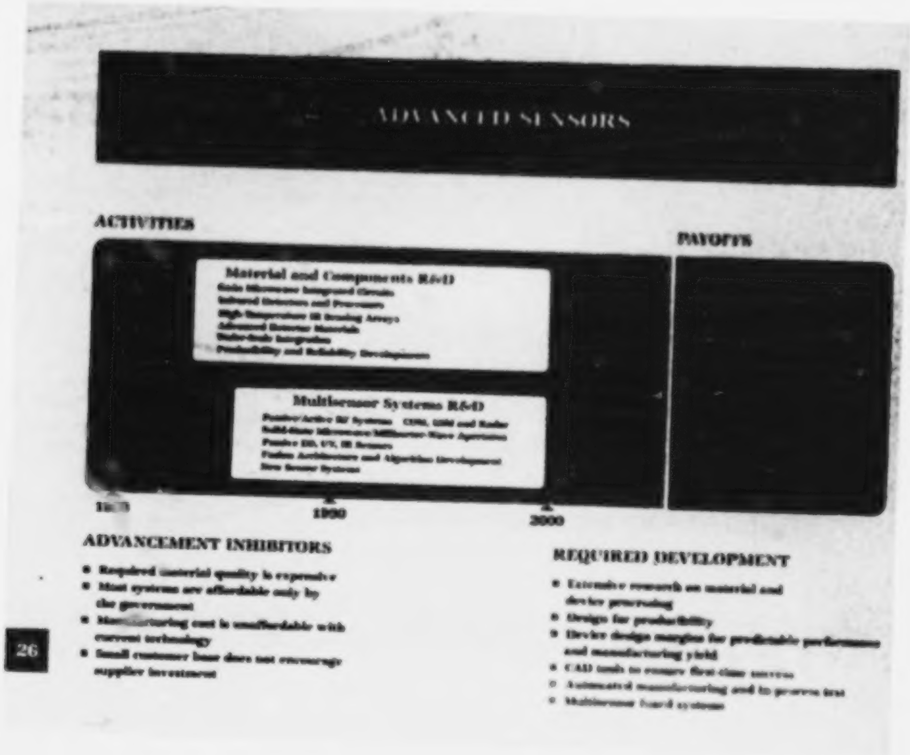
As the operational environment becomes increasingly complex, sensors will have to detect and relay more and more information related to flightpath selection. Certainly future scenarios imply a critical need for more effective and affordable sensors. Strategic systems, including the Strategic Defense Initiative, demand sensors that automatically detect and identify very distant threats. For survivability of aircraft operating at low altitude, all threats must be sensed, recognized and countered automatically or presented to the pilot for verification and immediately counteraction.

Advanced sensors can aid both commercial and military aviation by providing increased flight safety and performance. Further development of this technology could also enable the design of much lighter weight, more affordable and reliable onboard equipment for a variety of applications.

Significant advances have recently been made in both high-performance infrared detectors, radar transceiver components and laser sensors. Proof-of-concept work needs to proceed. Improved sensor arrays have not yet been produced in great enough numbers to accurately measure their reliability. For these components to be broadly used, production costs must be significantly decreased.

Emphasis is being placed on linear gallium arsenide through the MIMIC program, and infrared has been highlighted by the Defense Projects Engineering Standards Office thrust. However, a continuing focus is required across a broader front, especially in infrared and fused sensor systems, to seize and widen our initiative.

Compared to the level of sensor technology development held by several other major world powers, U.S. development is lagging. For example, as a result of advances in IR and radar sensor technologies made by France and the United Kingdom, we no longer have a competitive edge within NATO. The U.S.S.R. and certain other Iron Curtain countries announced significant breakthroughs in other sensor technologies in the early part of this decade; they have since halted publication of their research, but we must assume that they are at least competitive. If the United States is to be a leader in military and commercial sensor development, immediate emphasis must be placed on this technology.



ADVANCED SENSORS

ACTIVITIES

Material and Components R&D

GaAs Microwave Integrated Circuits
Infrared Detectors and Processors
High Temperature IR Sensing Arrays
Advanced Detector Materials
Wafer-Scale Integration
Producibility and Reliability Development

Multisensor Systems R&D

Passive/Active RF Systems - CNI, EW and Radar
Solid-State Microwave/Millimeter-Wave Apertures
Passive EO, UV, IR Sensors
Fusion Architecture and Algorithm Development
New Sensor Systems

1985 1990 2000

PAYOFFS

ADVANCEMENT INHIBITORS

- Required material quality is expensive
- Most systems are affordable only by the government
- Manufacturing cost is unaffordable with current technology
- Small customer base does not encourage supplier investment

REQUIRED DEVELOPMENT

- Extensive research on material and device processing
- Design for producibility
- Device design margins for predictable performance and manufacturing yield
- CAD tools to ensure first-time success
- Automated manufacturing and in-process test
- Multisensor fused systems

ADVANCED SENSORS

RECOMMENDATIONS

- Develop advanced systems architecture directed at multisensor solutions to overcome basic limitations of standard sensors
- Develop multiapplication microwave-millimeter wave integrated circuits needed to support these multisensor systems
- Develop multiapplication, high-performance focal plane arrays based on recent breakthroughs
- Explore and broaden sensor spectral limits beyond current areas, including future breakthroughs anticipated through developments in high-temperature superconductive materials
- Incorporate the new arrays and integrated circuits into integrated avionics systems for stealth, force multiplication and affordability

MAJOR BENEFITS

[illegible]

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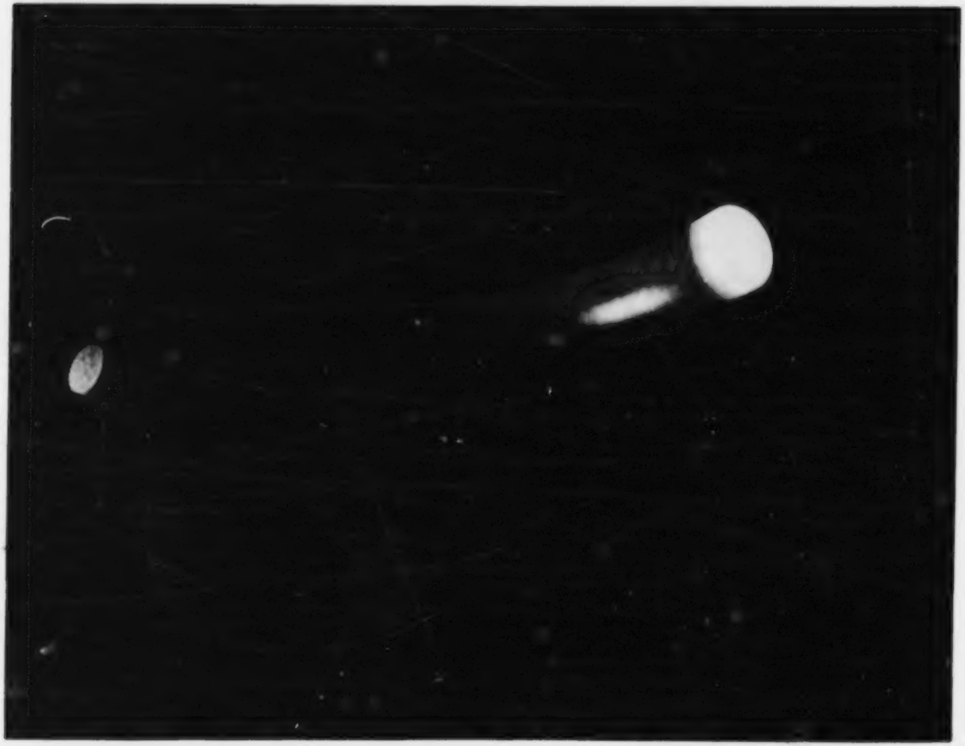

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OPTICAL INFORMATION PROCESSING

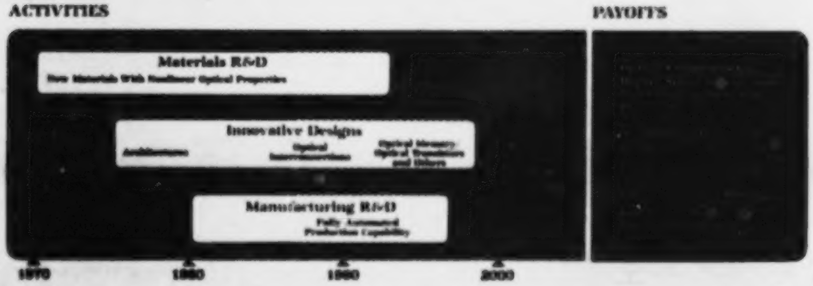
Early in the 21st century, aerospace information processing requirements may exceed the practical performance and reliability limits of conventional electronics. Fortunately, the use of optical information processing, as compared to current electronic methods, is expected to provide a thousandfold improvement in performance and possibly reliability as well.

Optical information processing is concerned with the storage and manipulation of data by optical devices. This technology includes signal, image, numerical data and symbolic data processing. The key to this new technology is the use of light as opposed to the charged electron flow used in conventional electronics. The electromagnetically neutral light particles, or photons, move much faster and are unaffected by electromagnetic interference or strong electromagnetic pulses. Since virtually all types of future aerospace systems will require much faster real-time information processing, optical information processing is of global interest.

Current technology development is focusing on two approaches. For the near term, optoelectronics, a blend of optical methodologies, electronic methodologies and optical interconnection techniques, offers the potential of a smooth technological transition from electronics to pure optics. For the longer term, researchers are working on the development of an "optical transistor." This device will form the basis for optical integrated circuits and memory devices.

Recent advances in the three major areas of materials and devices technology, algorithm development and system architectures should help to produce machines capable of greater information processing capability in the next several years. The successful integration of optical data processors into commercial and military systems will depend heavily on continued research. With an increase in resources, the development time could be reduced by 25% or more. This could provide an optoelectronic solution within 10 years and an all-optical solution within 20 years.

OPTICAL INFORMATION PROCESSING



ACTIVITIES

PAYOFFS

Materials R&D
New Materials With Nonlinear Optical Properties

Innovative Designs
Architectures
Optical Interconnections
Optical Memory, Optical Transistors and Others

Manufacturing R&D
Fully Automated Production Capability

ADVANCEMENT INHIBITORS

- Technical maturation is slow
  - Material/processes still evolving
  - Customers slow to accept
- Insufficient technology transfer
  - Each company tends to "do their own thing"
  - DOD data transfer to industry
- High costs
  - Specialized material compounds
  - Construction of clean room facilities
- Shortage of skilled engineers and technicians

REQUIRED DEVELOPMENT

- Specialized material compounds with nonlinear optical properties
- Creation of optical system architectures
- Innovative, low-cost manufacturing methods
- Simplified repair methods
- New, innovative device component designs

OPTICAL INFORMATION PROCESSING

RECOMMENDATIONS

- Increase R&D emphasis on both optoelectronics and optical approaches
- Develop skilled human resources for all levels: R&D, engineering and manufacturing
- Attempt integration with real systems that require optical information processing beyond the capabilities of conventional electronic processors
- Establish and prioritize real-system requirements that go beyond requests for "more speed and parallelism"
- Form private U.S. consortiums to address specific technical issues but with direct ties to:
  - Key DOD agencies
  - Key technical universities

MAJOR BENEFITS

[illegible]

	Applications				
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	●	●	●	●	●
[illegible]	●	●	●	●	●
[illegible]	●		●		●
[illegible]	●	●	●	●	●

ARTIFICIAL INTELLIGENCE

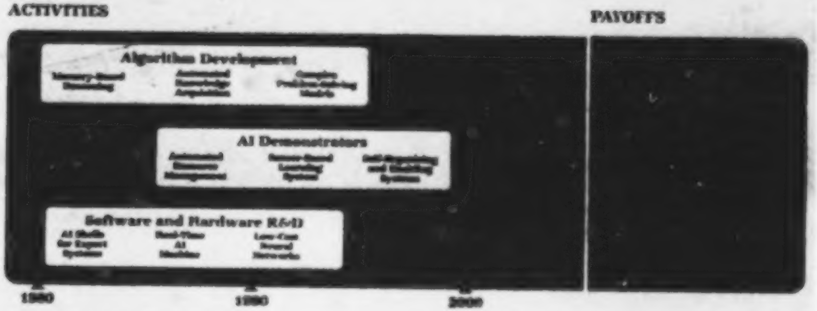
History may judge artificial intelligence (AI) to be the most pivotal technology of this century. The success of many U.S. efforts is dependent upon computers that evaluate complex situations; therefore, the progress of AI development is crucial.

This advanced technology is concerned with complicated data processing problems and the development of problem-solving capabilities that elaborate on a model of human intelligence. AI covers a number of computer-based activities, one of the most common being the design of "expert" systems. Traditional computing techniques required hours of laborious programming to load a data base with all possible solutions to each problem. In today's expert systems, computers use selected knowledge from one or more human experts to solve problems in much the same way as a human might. The only drawback is that such a system only "learns" from new human input. Future AI systems will be capable of machine learning; their data bases will be continuously updated by the outcome of their own problem-solving operations.

The impact of AI technology on both military and civilian aerospace systems will be considerable. Human productivity will be increased, system performance and reliability will be improved and life cycle costs will be reduced. By the turn of the century, applications of AI are expected to revolutionize a variety of aerospace products, as well as the way in which these products are manufactured.

Applications of AI technology are heavily dependent on the availability of other newly emerging key technologies, such as advanced computer software. AI will also be easier to implement with further development of computer hardware, very large scale integrated circuitry and optical information processing. We need to encourage further advances in both computing hardware and theory, as well as develop demonstrators to illustrate AI applicability as the technology moves from theory to practice. Despite strong challenges from the Soviets and the Japanese, the United States still enjoys a lead in this technology, but without focused attention this lead will undoubtedly disappear.

ARTIFICIAL INTELLIGENCE



ACTIVITIES

PAYOFFS

Algorithm Development

Memory-Based Reasoning
Automated Knowledge Acquisition
Complex Problem-Solving Models

AI Demonstrators

Automated Resource Management
Sensor-Based Learning System
Self-Organizing and Modifying Systems

Software and Hardware R&D

AI Shells for Expert Systems
Real-Time AI Machines
Low-Cost Neural Networks

1980
1990
2000

ADVANCEMENT INHIBITORS

- Insufficient knowledge of human problem-solving process
- New AI technologies suffer from:
  - Unpredictable performance
  - Lack of design tools that need to be developed and proven
  - Different risk perceptions between AI and system developers
  - Divergence between academic and nonacademic technology trends

REQUIRED DEVELOPMENT

- Ultrareliable software validation methods for expert systems
- Advanced computer system for problem formulations, solution design and software design, development and maintenance
- Improved techniques for modeling and processing information contaminated by uncertainty
- Software capable of commonsense reasoning

ARTIFICIAL INTELLIGENCE

RECOMMENDATIONS

- Place more emphasis on relevant, real demonstrators to encourage acceptance by system developers and enable AI to become specific in real systems
- Encourage AI content in selected systems, as with automation and robotics, for space station
- Expand government-sponsored industry internship programs for university faculty members on sabbatical
- Using the Software Engineering Institute as model, organize similar efforts to encourage communication between AI, data based management systems and software engineering technologies

MAJOR BENEFITS

Applications of artificial intelligence will result in revolutionary productivity improvements for man-machine systems

	Applications				
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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ULTRARELIABLE ELECTRONIC SYSTEMS

The next generation of flight control systems will require a level of reliability that far surpasses today's capabilities: a maximum of only one total system failure will be allowed for every 100,000 years of continuous system operation. Although the reliability of electronics has improved remarkably over the past 25 years, the increasing complexity of system designs demands that much greater emphasis be placed on the development of methodologies for producing provably correct designs for ultrareliable systems.

Currently, the reliability of a new system cannot be adequately predicted because the prediction methodology and simulation for complex systems is still too imprecise. We know too little about system failure modes to correctly focus efforts on reliability during system design. Methodologies are needed to design effective environmental testing. Fault-tolerant architectures, hierarchical maintenance systems and self-healing systems are still evolving.

Achievement of ultrareliable electronic systems (URES) requires improvements in many separate technologies. In particular, advancements in the other five electronic technologies described in this brochure are essential for URES. Learning how to blend the applications of these technologies will further enhance our ability to increase the reliability of complex systems.

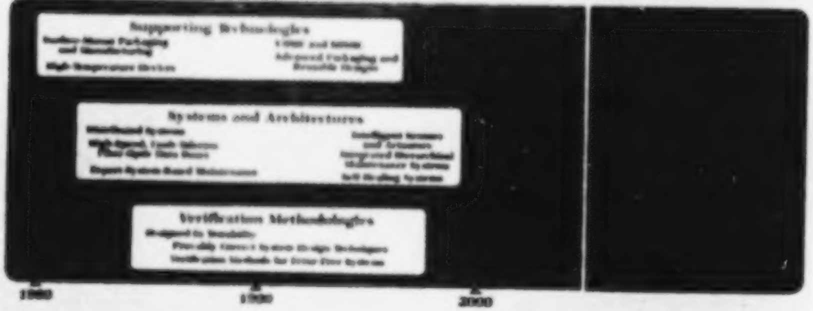
Today, a tenfold improvement can be achieved in reliability, but the price is high. In space and strategic applications, for example, components go through extensive screening, special production lines are established, lengthy testing procedures are employed and multiple redundancy is used for subassemblies. Accordingly, one goal of this key technology is to achieve greatly increased reliability, but at an affordable cost.

The benefits of URES are applicable to an imposing array of vehicles and platforms. Greatly improved electronic reliability contributes to cost reductions in military and commercial applications, longer life and operability in space and surveillance applications, and increased safety in critical process-control applications. However, the attainment of these benefits will only be ensured by a long-term R&D effort in URES and related technologies. In addition, we recommend that the development of URES be addressed in a cooperative effort on a national level to ensure improvement in the manner in which systems are specified, procured and certified.

ULTRARELIABLE ELECTRONIC SYSTEMS

ACTIVITIES

PAYOFFS



Supporting Technologies

Surface-Mount Packaging and Manufacturing

High-Temperature Devices

VHSIC and MIMIC

Advanced Packaging and Reusable Designs

Systems and Architectures

Distributed Systems

High-Speed, Fault-Tolerant Fiber-Optic Data Buses

Expert-System-Based Maintenance

Intelligent Sensors and Actuators

Integrated Hierarchical Maintenance Systems

Self-Healing Systems

Verification Methodologies

Designed-In Testability

Provably Correct System Design Techniques

Verification Methods for Error-Free Systems

ADVANCEMENT INHIBITORS

- Continuing dependence upon costly and massive redundancy
- Lack of quantitative understanding of relationships between reliability and environment
- Microsystem management philosophy vs. a systems approach

REQUIRED DEVELOPMENT

- Packaging and manufacturing technology (e.g., SMT, VLSI, VHSIC and MIMIC)
- Methods for designing and testing error-free systems and environmental test screening
- Hardware and software failure models and system reliability prediction methodology
- Advanced CAD tools for simulation
- Self-healing and automated maintenance

ULTRARELIABLE ELECTRONIC SYSTEMS

RECOMMENDATIONS

- Promote an integrated reliability management approach emphasizing reliability methodologies, initiatives and contractual approaches
- Emphasize proven components and software designs, as well as self-test capability
- Develop viable, rapid simulation and prototyping capability for achievement of error-free designs
- Accelerate development of advanced automated design, test and manufacturing analysis methods

MAJOR BENEFITS

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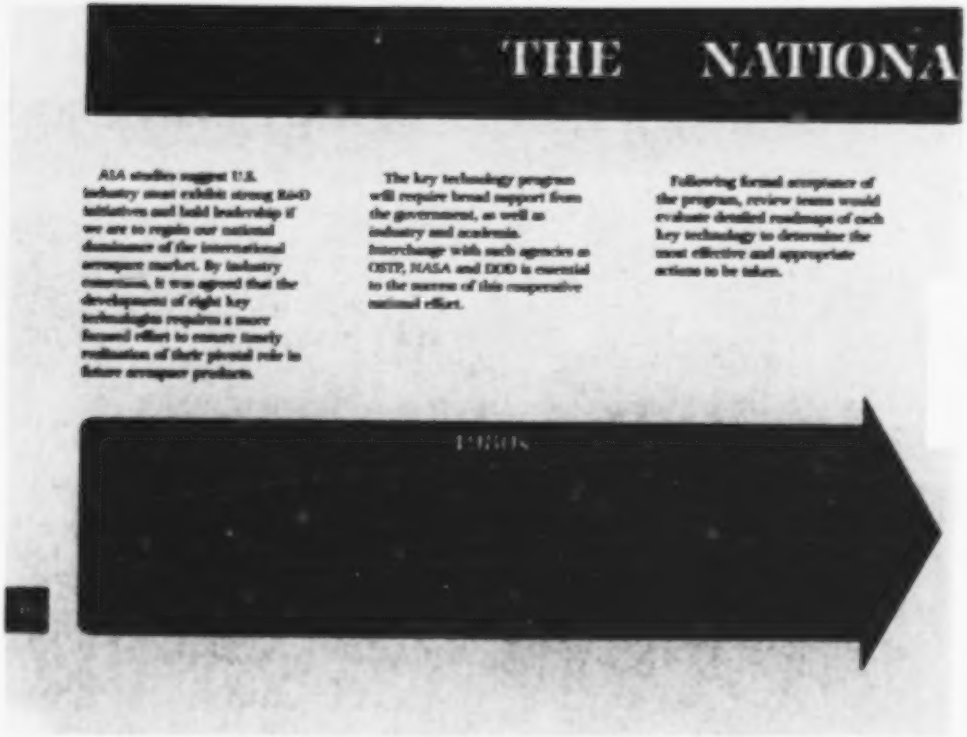


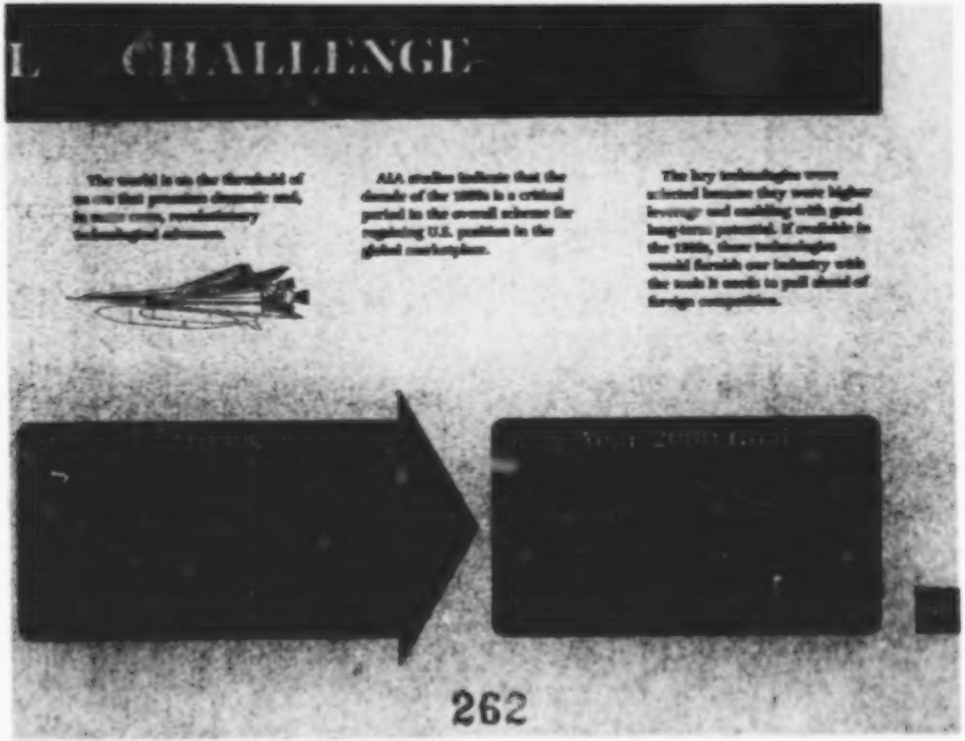
THE NATIONA

AIA studies suggest U.S. industry must exhibit strong R&D initiatives and bold leadership if we are to regain our national dominance of the international aerospace market. By industry consensus, it was agreed that the development of eight key technologies requires a more focused effort to ensure timely realization of their pivotal role in future aerospace products.

The key technology program will require broad support from the government, as well as industry and academia. Interchange with such agencies as OSTP, NASA and DOD is essential to the success of this cooperative national effort.

Following formal acceptance of the program, review teams would evaluate detailed roadmaps of each key technology to determine the most effective and appropriate actions to be taken.

1990s



L CHALLENGE

The world is on the threshold of an era that promises dramatic and, in many cases, revolutionary technological advances.

AIA studies indicate that the decade of the 1990s is a critical period in the overall scheme for regaining U.S. position in the global marketplace.

The key technologies were selected because they were higher leverage and enabling with good long-term potential. If available in the 1990s, these technologies would furnish our industry with the tools it needs to pull ahead of foreign competition.

SUMMARY

The erosion of the competitive position of the U.S. aerospace industry needs immediate attention by national leadership. Current policies will not put the U.S. in a leadership position in the world aerospace industry.

Better and more cohesive national policies must be established immediately if they are to provide turn-of-the-century benefits, both to our economy and to our national security.

Initiating a strong U.S. technology development effort requires the creation of a new, long-term national perspective. This is much too large an undertaking for industry alone. If U.S. competitiveness is to be enhanced, industry, government and academia must renew the national spirit of cooperation and partnership to facilitate the prioritizing and focusing of effort.

The challenge is to make such an organized national effort work as never before in peacetime.

In the aerospace industry, technology development is the key to international competitiveness.

We see three major results as potential payoffs of a nationally focused technology program. ***First, there will obviously be a more rapid maturation of priority technologies. Second, better and more cohesive policies will be established to enhance the entire national technology development process. Finally, markedly superior new products will become available by the turn of the century.***

Only if government and industry move promptly, as members of a team, will these statements become realities.

This is a long-term effort, and more than a decade will pass before most of the major technological benefits are available to new products. Considering the rate of their technology expansion, the position of our foreign competitors in the world market will most likely continue to improve. The Aerospace Technical Council offers immediate leadership to initiate and sponsor joint meetings between government, industry and university representatives. If we are to accept this international challenge, a dynamic and cooperative new national effort must be initiated immediately.

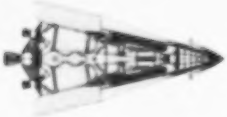
RECOMMENDATIONS

To meet the goal of regaining worldwide U.S. aerospace product superiority by the turn of the century, the AIA Aerospace Technical Council recommends that:

- A national aerospace key technology program, led by industry, endorsed by government and supported by academia, be immediately undertaken
- All parties should assign high priority to this national program, at both policy and technical levels
- Cooperative ways should be sought to facilitate and encourage this unique technology development effort through new actions and approaches
- The aerospace industry should provide its collective design and manufacturing experience and its long-term focus on international competitive challenges

"A strategic focus on key technologies is critical to U.S. leadership in the competition of new products in the global marketplace. As a nation, we must get started now."

Don Fuqua, President
Aerospace Industries Association



AIA KEY TECHNOLOGIES RESOLUTIONS

WHEREAS: *Development of advanced technologies is key to the future global competitiveness of U.S. aerospace products, and*

WHEREAS: *The aerospace industry has declared its firm commitment to foster and support a bolder national research and development program, and*

WHEREAS: *Immense benefit to U.S. national security and international trade can be realized through a cooperative national technology development program endorsed by U.S. government and supported by academia.*

NOW, THEREFORE, BE IT RESOLVED: *That the Board of Governors of the Aerospace Industries Association of Amercia hereby endorses and supports the proposal for national action initiated by the AIA Aerospace Technical Council and entitled Key* ***Technologies for the 1990s.***

BE IT FURTHER RESOLVED: *That the aerospace industry will provide its available resources and leadership to work cooperatively with government and academia to attain the Key* ***Technologies for the 1990s*** *goal of ensuring worldwide U.S. aerospace product superiority by the end of this century.*

Unanimously adopted by the AIA Board of Governors, November 21, 1987.

KEY TECHNOLOGIES FOR THE 1990s

Aerospace Industries Association of America, Inc.

A Detailed Technology
Roadmap for:

ROCKET PROPULSION

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1 OCTOBER 1988

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FOREWORD TO THE
AIA KEY TECHNOLOGIES FOR THE 1990s
INITIATIVE

Background

The United States technological superiority in aerospace products and military capability is being severely challenged. Although the industry has consistently maintained a substantial positive trade balance of over $10 billion in recent years, aerospace imports are growing rapidly and U.S. aerospace competitiveness is eroding.

Our national defense requires affordable systems and a robust industrial capability to support it. Our national economic well-being depends on internationally competitive, high-quality, technologically superior products which create industrial health leading to more jobs, a larger tax base, and positive trade balances. An important and viable option for achieving these goals is a bold innovative national aerospace technology development program which builds on the technological superiority we now enjoy.

The AIA Proposal

The Aerospace Industries Association (AIA) initiative, called *Key Technologies for the 1990s*, proposes a three-pronged national strategy with the goal of ensuring U.S. technological superiority in aerospace products and military capability well into the 21st century. The first element of this thrust is to create a cooperative national effort among industry, government, and academia to focus on the development of selected key technologies. The second is to cooperatively mold innovative policies that will stimulate technology development and facilitate its rapid application to new commercial and military products. The third element will focus on development of methodologies, tools, and disciplines required to increase the competitive advantage of our technology base. AIA is committed to a leadership role, working cooperatively with government and universities.

Key Technologies List

Over the past few years senior technologists in the AIA member companies (representing over $100 billion in sales in 1987) reviewed over 100 technologies for future applications to systems. During the past year, they achieved a consensus on eight key technologies which have the greatest potential for increasing the technological competitiveness of the U.S. These eight technologies were selected on the basis of highest leverage, greatest potential payoff, and broadest application, both commercial and military. If national focus can be attained, and if they can be protected from severe budgetary perturbations over the long haul, these eight key technologies will result in markedly superior products for the global marketplace. They are:

Composite Materials
Very Large-Scale Integrated Circuits
Software Development
Propulsion Systems
Advanced Sensors
Optical Information Processing
Artificial Intelligence
Ultrareliable Electronic Systems

AIA representatives have prepared a draft Roadmap for each of the eight key technologies. Working with government and university representatives, the Roadmaps are being validated, and then will be refined into Technology Development Plans. These Plans will give a joint perspective of the state of each technology, the plans for progress, resources currently being used, and those required to meet future goals.

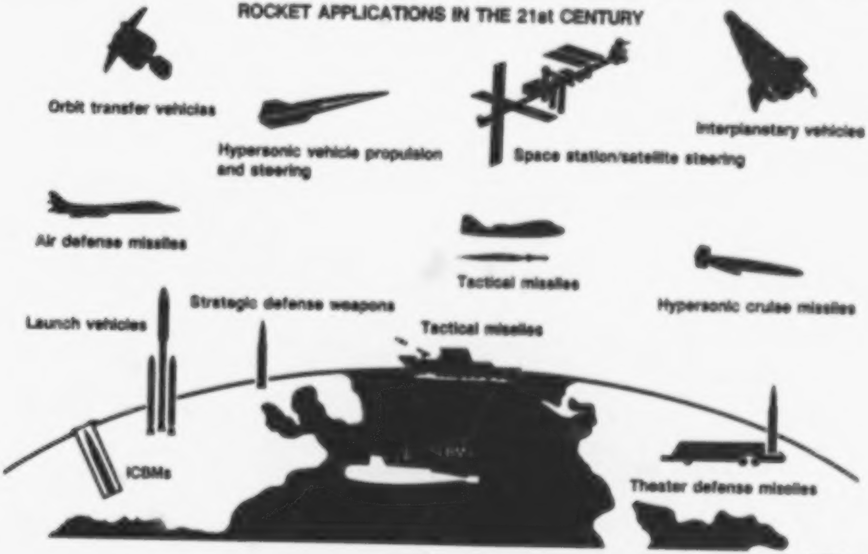
Implementation

AIA envisions a long-term effort to emphasize national development of the Key Technologies for the 1990s. Concurrent with the Roadmap evolution, a joint policy level group called the Aerospace Technology Policy Forum will oversee the technology team efforts and review regulations, policies, and legislation needed to facilitate technology development.

AIA needs and solicits strong legislative and executive department support for this program for national action. This proposal builds upon the technological leadership of the aerospace industry. U.S. worldwide competitiveness can be meaningfully enhanced if leaders of industry, government, and academia all work together toward renewing the national spirit of cooperation and partnership. The challenge is to make such an organized national technology development effort work as never before in peacetime.

ROCKET PROPULSION

ROCKET APPLICATIONS IN THE 21st CENTURY


Orbit transfer vehicles
Hypersonic vehicle propulsion and steering
Space station/satellite steering
Interplanetary vehicles
Air defense missiles
Tactical missiles
Hypersonic cruise missiles
Launch vehicles
Strategic defense weapons
Tactical missiles
ICBMs
Theater defense missiles

Introduction

In its simplest form, rocket propulsion is a type of jet propulsion where reaction (thrust) is developed by the momentum of ejected matter. As contrasted to gas turbine and ramjet propulsion, rocket propulsion carries, as an integral part of each system, its required fuel and oxidizer.

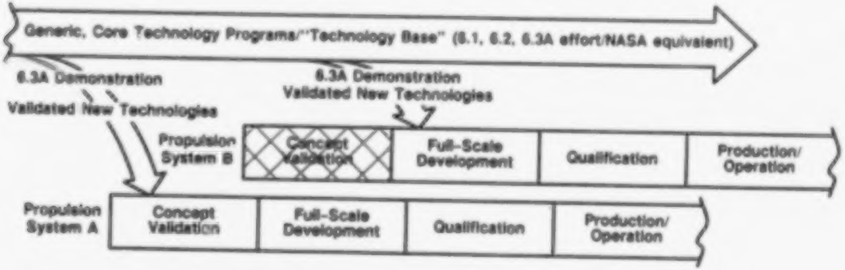
The majority of rocket propulsion systems can be subdivided into two categories: liquid or solid propellant. This Roadmap deals with each category separately. While both these forms of rocket propulsion share common objectives, their technology needs (except for some common materials) are different. Other forms of rocket propulsion, such as hybrid propulsion—combining various aspects of both solid and liquid propellant rockets—nuclear rockets, and combined-cycle systems, are not covered. However, the solid and liquid rocket technology gains will benefit other forms of rocket propulsion.

Since the early 1970s, most of our nation's rocket engine development programs have been forced to develop and/or validate critical technology during the full-scale engine development/production/operation phases or resort to 1960s technology, which increased development, production, and total life-cycle costs, or compromised mission capability. National goals for space and defense once again will demand continued improvement and development of rocket propulsion through the 1990s and beyond.

The objective of both the Liquid Rocket Engine and Solid Rocket Motor Technology Roadmaps is to establish and focus attention on generic, core technology programs which will yield validated design and fabrication advances for the nation's rocket programs prior to embarking on full-scale development programs. Producing the needed core technologies in this manner minimizes the risk in future rocket developments. In addition, foreign competition is real and increasing in viability. U.S. technology base support has eroded since the 1970s so that such support is currently inadequate and inconsistent. The nation's rocket propulsion supremacy is now threatened. Obtaining core technology in this timely fashion also ensures that the ultimate objectives in specific development programs of reliable, safe, high-performance, and cost-effective flight operation will be achieved and U.S. supremacy maintained.

ROCKET PROPULSION

TECHNOLOGY ADVANCEMENT FLOW



Generic, Core Technology Programs/"Technology Base" (6.1, 6.2, 6.3A effort/NASA equivalent)

6.3A Demonstration

Validated New Technologies

6.3A Demonstration
Validated New Technologies

Propulsion System B

Concept Validation | Full-Scale Development | Qualification | Production/Operation

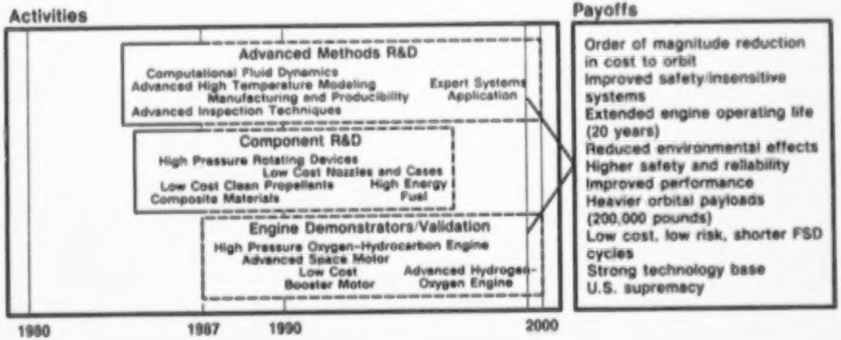
Propulsion System A

Concept Validation | Full-Scale Development | Qualification | Production/Operation

Payoffs:

- Strong technology base
- Reduce development risk, cost, schedule
- Maximize operational success

ROCKET PROPULSION



Activities

Advanced Methods R&D

Computational Fluid Dynamics
Advanced High Temperature Modeling
Manufacturing and Producibility
Advanced Inspection Techniques
Expert Systems Application

Component R&D

High Pressure Rotating Devices
Low Cost Nozzles and Cases
Low Cost Clean Propellants
Composite Materials
High Energy Fuel

Engine Demonstrators/Validation

High Pressure Oxygen-Hydrocarbon Engine
Advanced Space Motor
Low Cost Booster Motor
Advanced Hydrogen-Oxygen Engine

Payoffs

Order of magnitude reduction in cost to orbit
Improved safety/insensitive systems
Extended engine operating life (20 years)
Reduced environmental effects
Higher safety and reliability
Improved performance
Heavier orbital payloads (200,000 pounds)
Low cost, low risk, shorter FSD cycles
Strong technology base
U.S. supremacy

Required Development:

- Advanced automated methods
- Cost- and reliability-driven design methods
- Improved materials
- Improved manufacturing methods
- Improved safety/insensitive systems
- Nondestructive testing techniques
- Technology demonstrators

ROCKET PROPULSION

BENEFITS, APPLICATIONS, AND RECOMMENDATIONS

Benefits	Application				
	Space Launch Vehicles	Orbital Transfer Vehicles	Ballistic and Tactical Missiles	Space Interceptors	On-Orbit/ Planetary Vehicles
Improved Payload/Range	●	●	●	●	●
Reduced Maintenance	●	●	●		●
Improved Safety	●	●	●		●
Reduced Life-Cycle Costs	●	●	●	●	●
Extended Operating Life/Reusability	●	●	●		●
Reduced Development Time	●	●	●	●	●
Reduced Environmental Effects	●		●		

Recommendations:

- Reestablish a national commitment to foster the advances necessary to maintain technological excellence
- Expand national propulsion technology programs to advance analytical and computational methods
- Investigate new materials and fuels, methods of manufacture, and inspection techniques
- Expand health monitoring and control systems to enhance low cost operations
- Investigate combustion phenomena and advanced heat-transfer techniques
- Test engine demonstrators to verify technology gains
- Develop advanced automated design, manufacturing, test, and analysis method
- Develop reliability- and cost-driven design methodology
- Establish "specialized" national test facilities
- Establish a national materials data base

Safety and Environmental Concerns

The achievement of national objectives for rocket propulsion requires that both future liquid and solid propellant propulsion systems exhibit improved safety and environmental characteristics in manufacture, testing, and operations. This will require an extensive effort and must be a significant item in propulsion system design. The Pershing II incident in Germany (January 1985) and the Peacekeeper Stage I ignition during manufacture (December 1987) underscore the need to make safety a primary design consideration. In recognition of such considerations, hazard analyses must become a way of life! The emerging armed forces requirements for insensitive munitions must also be addressed.

In many respects and for some organizations, this will require a "design culture" change—the hazard analyst and safety engineer must be an integral part of future design teams every bit as important as the structural analyst, thermal analyst, propellant chemist, etc.

ROCKET PROPULSION

SAFETY AND ENVIRONMENTAL CONCERNS

- Material compatibility
- Impact/shock sensitivity
- Friction sensitivity
- "Fire" sensitivity
- Electrostatic discharge sensitivity
- In-process sensitivity
- Deflagration to detonation characteristics
- Liquid propellant leaks and spills
- Rocket exhaust environmental effects
- Payload contamination from rocket exhaust

Reliability versus "Cost of Failure"

Cost of failure is the price paid by the nation for a flight failure. There are several major elements of this cost other than the lost payload and launch vehicle. Failure investigations, delays in continuing operations, correction, and/or qualification of design changes necessary to resume flight operation can be a substantial percentage of the original DDT&E costs. These facts of life were clearly driven home by the 1985–86 Shuttle and Titan III flight failures with the aggregate costs being measured in billions of dollars.

Reliability and cost of failure have a major impact on system life–cycle costs. Avoidance or minimization of cost of failure requires designing reliability into the propulsion system. Designing to minimize or eliminate failure modes must be an integral part of each new system development. As with safety, the reliability engineer must be a part of the design team. Failure effects analyses must help guide design, not just document possible problem areas.

Although there are several reliability approaches to assist the developer, they are unevenly applied. The Air Force R&M 2000 program is one effort directed at increasing and improving their application. Successful "reliability" implementation will require "culture" changes. This Technology Roadmap process is one vehicle to facilitate such change. Without proper and significant attention to safety and reliability improvement, the value of other technology efforts is greatly diminished.

ROCKET PROPULSION

RELIABILITY CONCERNS

- Material/manufacturing process variability
- Tolerance interaction
- Component interaction(s)
- NDE capabilities/limitations
- System environment
- Aging effects
- Damage/defect/flaw tolerance
- Reliability design methodology, prediction, and validation
- Design margins
- Component redundancy

Rocket Technology Drivers

The technology drivers for the 1990s are established from projected mission requirements. Specifically considered were misions such as:

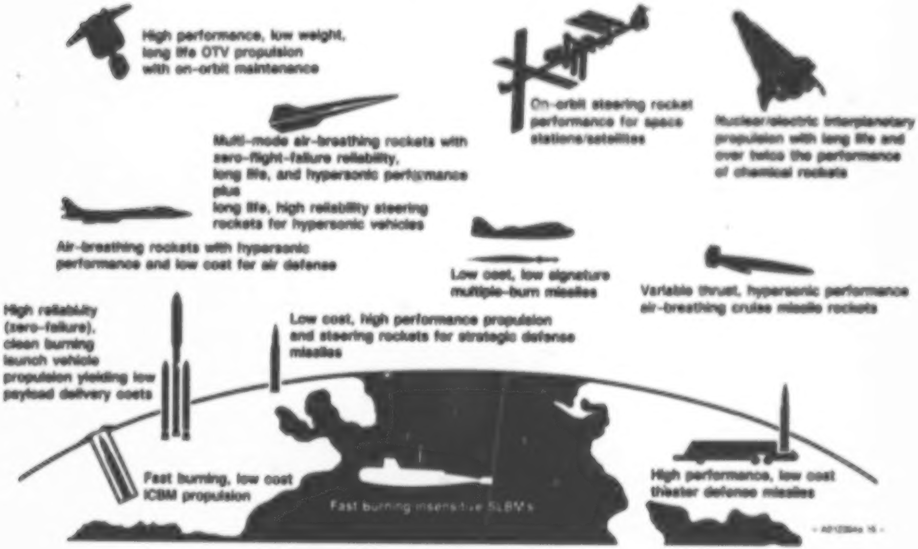
- Low cost/high reliability launch vehicles
- Orbit transfer vehicles
- Space station/satellite steering
- Interplanetary vehicles
- Hypersonic vehicles
- Hypersonic cruise missiles
- Fast burning ICBMs/SLBMs
- Strategic defense weapons
- Tactical missiles
- Theater defense missiles

Major driver will be, depending on mission:

- High performance
- Long life
- High reliability
- Multi-pulse operation
- Low cost
- Insensitivity
- Variable thrust

ROCKET PROPULSION

ROCKET TECHNOLOGY DRIVERS FOR THE 21st CENTURY


High performance, low weight,
long life OTV propulsion
with on-orbit maintenance
On-orbit steering rocket
performance for space
stations/satellites
Nuclear/electric interplanetary
propulsion with long life and
over twice the performance
of chemical rockets
Multi-mode air-breathing rockets with
zero-flight-failure reliability,
long life, and hypersonic performance
plus
long life, high reliability steering
rockets for hypersonic vehicles
Air-breathing rockets with hypersonic
performance and low cost for air defense
Low cost, low signature
multiple-burn missiles
Variable thrust, hypersonic performance
air-breathing cruise missile rockets
High reliability
(zero-failure),
clean burning
launch vehicle
propulsion yielding low
payload delivery costs
Low cost, high performance propulsion
and steering rockets for strategic defense
missiles
Fast burning, low cost
ICBM propulsion
Fast burning insensitive SLBM's
High performance, low cost
theater defense missiles

LIQUID ROCKET ENGINE TECHNOLOGY ROADMAP

Definition

Liquid rocket engines are heat machines which produce thrust by burning liquid propellants in a chemical reaction or by expelling pressurized gases which have been heated by nuclear reaction or electrical energy.

Liquid rocket engines may use one, two, or three propellants. The two basic types of engines are pressure-fed, in which propellants are delivered to the engine thrust chamber by pressurized tanks, and pump-fed, in which turbine-driven pumps provide propellant flow for the thrusters. Pump-fed engines have many variations depending on the methods used to generate and route the fluids which drive the turbines.

Key components of all liquid rocket engines are thrust chambers, thrust nozzles, propellant valves with actuators, propellant ducts, and thrust takeout structure. Engines may also include thrust vector control (TVC) apparatus, engine sensors, electronic controls, and propellant pumps with drive turbines.

This Technology Roadmap describes the needed core technologies which are generic and applicable to all forms of liquid rocket engines. The Roadmap also includes technologies for chemical reactions of propellants (combustion and catalytic devices), but does not cover the technologies for nuclear reaction or electrical energy heat sources.

Completed and ongoing government studies related to advanced propulsion technology needs for future U.S. space and defense programs have been considered during the preparation of this Roadmap.

LIQUID ROCKET ENGINES

DEFINITION

- **Liquid Rocket Engines**
  - **Chemical**
  - **Nuclear**
  - **Electric**

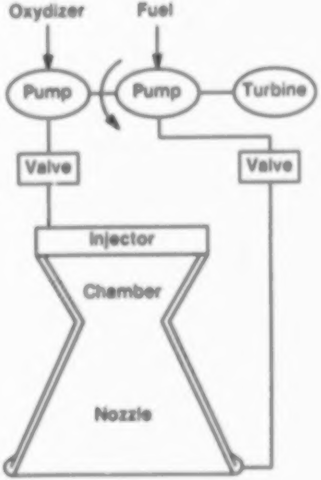
Energy Source ⇒ **Chemical**

Combustion Devices
Catalytic Devices

COMPONENTS

All Engines
- Injector
- Thrust Chamber/Nozzle
- Thrust Nozzles
- Valves/Actuators
- Ducts
- Structure

Some Engines
- Thrust Vector Control
- Sensors
- Controllers
- Turbopumps


Oxydizer
Fuel
Pump
Pump
Turbine
Valve
Valve
Injector
Chamber
Nozzle

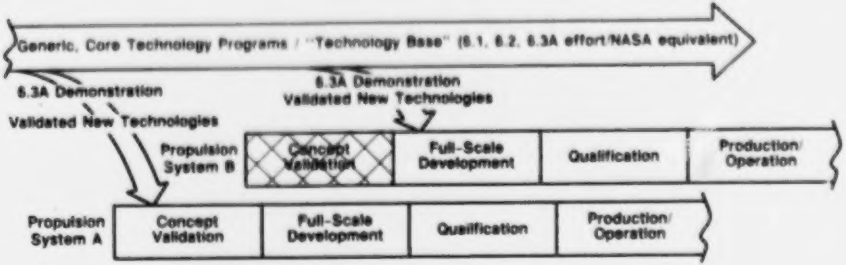
Technology Advancement Flow

Most of our nation's previous aerospace development programs have been forced to develop and/or validate critical technology during the full-scale engine development, production, and operation phases, which frequently increased development, production, and total life-cycle costs, or compromised mission capability.

The objective of the Liquid Rocket Engine Technology Roadmap is to establish generic, core technology programs which yield a validated technology base for the nation's rocket engine programs prior to embarking on full-scale development programs. Producing the needed capabilities in this manner minimizes the risk in future engine programs, yielding significant benefits in reduced cost and schedule and in safe, reliable flight operations.

LIQUID ROCKET ENGINES

OPTIMUM TECHNOLOGY ADVANCEMENT FLOW


Generic, Core Technology Programs / "Technology Base" (6.1, 6.2, 6.3A effort/NASA equivalent)
6.3A Demonstration
Validated New Technologies
6.3A Demonstration
Validated New Technologies
Propulsion System B
Concept Validation
Full-Scale Development
Qualification
Production/ Operation
Propulsion System A
Concept Validation
Full-Scale Development
Qualification
Production/ Operation

Payoffs:
- Strong technology base
- Reduce development risk, cost, schedule
- Maximize operational success

Technology Elements

These elements constitute areas which will provide the high leverage necessary for the advancement of this technology area. System concepts exist to produce the advances demanded by the challenging missions now being defined. However, the sophistication of the rocket engine solutions under study requires costly analytical techniques, making research and development (R&D) increasingly expensive. Algorithm development to simplify the analytical processes would greatly accelerate the entire development cycle. Similarly, new propellants and operating regimes have stressed our understanding of combustion stability, emphasizing the need to coalesce fluid dynamic and combustion analysis.

The cost of failure and national pressure for failure-free operation of large rocket vehicles demand that we assure the public, as well as ourselves, that new propulsion systems are highly reliable. To do this we must incorporate reliability into design, development, and manufacturing processes. This will require adaptation and use of statistical methods, such as those proven to be successful for automotive and electronic products, and a new emphasis on "reliability thinking" on the part of rocket design, development, and manufacturing engineers.

The remaining elements are hardware-oriented, consisting of basic building blocks of liquid rocket design and fabrication. Although high-strength, high-temperature, and heat-conductive materials exist, few are available that possess all three properties simultaneously. In addition to development of the materials themselves, determination of a broad range of properties is necessary to support the analytical processes discussed above. The seemingly mundane subject of bearings and seals is, instead, a technology driver for the contemporary liquid rocket engine's high-speed, high-pressure turbomachinery. Health monitoring and control will apply electronic and sensor technology for self-diagnosis and correction of preflight and flight anomalies. Fabrication processes, primarily conventional welding and brazing, are no longer capable of supporting the joining requirements of liquid rocket engines. Finally, system components and integration covers advances in tank materials, pressurization systems, and loading, chilling, and vent systems.

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LIQUID ROCKET ENGINES

TECHNOLOGY ELEMENTS

- Analytical representations
- High pressure combustion dynamics
- Reliability techniques
- Materials technologies unique to liquid rocket engines
- Bearings and seals
- Fabrication processes
- Engine health monitoring and control
- System components and integration

Technology Elements, Trends, and Milestones

The first three elements involve analytical techniques, which, as they advance, extend our ability to try out ideas on paper, allowing us to move into the more expensive hardware activities with increased confidence. The thrust of this work is twofold: to expand the application of techniques such as reliability analysis and computational fluid dynamics, and to combine disciplines such as combustion stability and heat transfer into an integrated model. Another example is the integration of high-temperature nonlinear material stress/strain behavior into finite element structural analysis computer codes. Currently, these are done serially, at considerable cost in resources and time.

The next five areas are hardware and integration elements related to the temperature and pressure stresses of rocket engines and the system aspects of propulsion. As engine performance improves, the temperatures and pressures drive materials toward composites. The increased capabilities thus enabled overstress conventional bearings and seals, requiring a shift to noncontact concepts which avoid the wear associated with rolling contact designs. The health monitoring task is intended to enable real-time assessment of engine status and, ultimately, to provide for real-time correction. As new materials evolve, joining processes—welding and brazing—are moving in new directions to remain abreast of rocket engine requirements. The remaining elements of the propulsion system are noted in the fifth area and their contribution is critical of the overall system effectiveness in the 1990s.

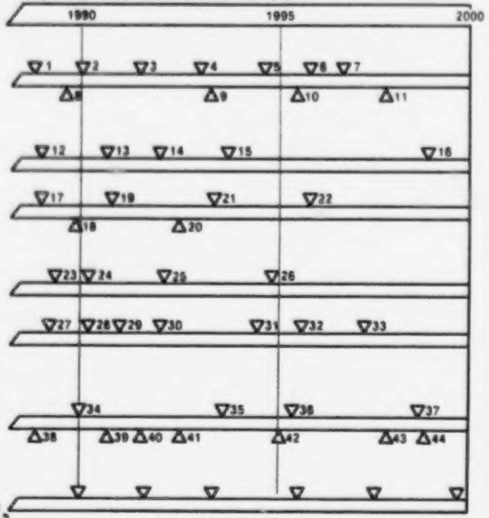
The validation element includes the demonstration of technology developments in test-bed engines and components.

All elements, trends, and mileposts shown pertain to technology development with current state-of-the-art propellants. The Key Technologies program will also include an alternate propellant technology element which includes slush hydrogen, gelled propellants, slurried propellants, high-energy/high-density propellants, and alternate state propellants. As alternate propellant technologies prove practical, they will be incorporated into the appropriate analytical/hardware technology element.

LIQUID ROCKET ENGINES

TECHNOLOGY ELEMENTS, TRENDS, AND MILESTONES*

TECHNOLOGY ELEMENTS	TREND
Analytical Representations	Increased application of computer-aided modeling techniques
Pump/Turbine Flow Analysis	Navier-Stokes CFD codes
Combustion Dynamics	Development of coupled combustion and gas-dynamic analyses
Liquid Rocket Materials	Metal matrix for heat transfer High strength composite turbopumps
Bearings and Seals	Fluid-film bearings Solid lubrication Near contact face seals
Fabrication Processes	Robotics and adaptive control Laser welding Ceramic joining
Engine Health Monitoring/Control	Low cost electronic controllers Engine condition monitoring Integrated condition monitoring/control
Propulsion System Components and Integration	Low cost hardware Easy assembly High reliability Low maintenance
Validation	Demonstration engines/components Mission simulated conditions



Δ/∇ Indicates completion of 6.2 and 6.3 effort or equivalent

* For current propellants; alternate propellants will also be considered

Note: The above technologies will be validated by demonstrations in component and/or engine test beds

TECHNOLOGY ELEMENTS AND MILESTONES

Analytical Representations	1	Automated grid generation, 1989
	2	2D and 3D chemistry codes, 1990
	3	Integrated design/models analysis, 1992
	4	Advanced graphics, 1993
	5	Dynamic grid generation, 1994
	6	Nonlinear material stress codes, 1996
	7	Advanced physical models in 3D codes, 1997
Pump/Turbine Flow Analysis	8	Time-averaged codes, 1989
	9	Time-dependent codes, 1993
	10	Improved turbulence models, 1996
	11	Direct design code, 1998
Combustion Dynamics	12	2D stability model, 1989
	13	3D stability model, 1991
	14	2D code verified, 1992
	15	3D code verified, 1994
	16	Performance/stability/heat transfer model, 1999
Liquid Rocket Materials	17	Copper-X alloys, 1989
	18	Composite nozzles, 1990
	19	High temperature metal matrix composites, 1991
	20	Composite propellant vessels, 1993
	21	Defect tolerant design methods, 1994
	22	Ceramic matrix composites, 1996

TECHNOLOGY ELEMENTS AND MILESTONES (Cont)

Bearings and Seals	23	Hydrostatic bearings, 1989
	24	Face seals, 1990
	25	Solid lube bearings, 1992
	26	Magnetic bearings, 1995
Fabrication Processes	27	Robotics, 1989
	28	CO_2 laser, 1990
	29	Fiber transmitted laser, 1991
	30	Intermetallic and ceramic joining, 1992
	31	Welding in space, 1994
	32	Advanced laser welding, 1996
	33	Advanced ceramic joining, 1997
Engine Health Monitoring/Control	34	Advanced architecture engines, 1990
	35	Advanced sensors/signal controllers, 1994
	36	Integrated health monitor/controller, 1995
	37	"Expert systems" controller, 1999
Propulsion System Components and Integration	38	AI propellant tanking, 1989
	39	Low cost, large scale propellant tankage, 1991
	40	Large scale electromechanical actuators, 1992
	41	AI pressurization components, 1993
	42	Integrated health monitoring/smart bit propellant system, 1995
	43	Low-g design software, 1996
	44	Orbital propellant transfer devices, 1999

Technology Projections

The technologies discussed in this Roadmap are basically tools rather than end-item hardware. However, these tools provide the capability to significantly reduce cost and risk, and to improve operating life, reliability, and vehicle performance. Unfortunately, in the press of allocating limited engine program resources, improved tools are often considered expendable because neither resources nor time are available to determine requirements, synthesize concepts, and develop, characterize, and demonstrate them to the point of usefulness to the program.

Fortunately, these techniques and materials lend themselves to cooperative activities and development can proceed without association with any particular application. The activities cited are intended to simplify the techniques by which analytical methods are applied to a development project and to develop ways in which analytical methods may be combined to solve complex combustion problems. Such analyses provide insights to the designers, with resulting economies in hardware fabrication and testing. The materials and fabrication process efforts proposed will enable performance and reliability increases necessary for an order of magnitude reduction in the cost of payload in orbit.

LIQUID ROCKET ENGINES

TECHNOLOGY PROJECTIONS

Technology Elements	Application	Benefits
Analytical Representations	Strength and life prediction	Longer operating life, greater reliability, reduced cost
Pump and Turbine Flow Analysis	Turbomachinery	Lower life-cycle cost, reduced development risk and schedule, increased reliability, improved performance
Combustion Dynamics	Combustion stability and efficiency analysis	Reduced development risk, time, and cost; increased performance
Liquid Rocket Materials	Improved thrust chamber cooling, lightweight turbopump, composite thrust chambers	Longer operating life, increased performance
Bearings and Seals	Turbomachinery	Longer operating life, increased reliability and performance
Engine Health Monitoring and Control	Reusable, long life engines	Lower life-cycle costs; improved reliability, safety, and maintainability
Fabrication Processes	Component fabrication, engine assembly and in-space joining	Reduced production and operation cost, increased reliability, repairs on space-based hardware

Benefits and Applications

U.S. space and defense objectives create the need to develop a number of new liquid rocket engines for use in the next century.

By conducting the Liquid Rocket Engine Technology Roadmap program in the 1990s, the nation will be able to achieve the technical propulsion objectives for our next century space and defense programs with the lowest possible life-cycle costs.

LIQUID ROCKET ENGINES

BENEFITS AND APPLICATIONS

Benefits		Application				
		Space Launch Vehicles	Orbital Transfer Vehicles	On-Orbit/ Planetary Vehicles	Ballistic and Tactical Missiles	Strategic Defense Missiles
Improved Payload/Range		AR,CD,MT	AR,CD,MT	MT	AR,MT	MT
Lower Life-Cycle Costs	Reduced Maintenance	MT,SB,HM	MT,FP		MT,FP	
	Eliminate Operations Failures	SB,HM	SB,HM	HM	MT	MT,FP
	Extended Operating Life/Reusability	SB,HM	SB,HM	HM		MT,FP
	Reduced Development Cost/Time	AR,CD, MT,FP	AR,CD, MT,FP	CD	AR,CD	AR,CD

AR = Analytical Representations
CD = Combustion Dynamics
MT = Materials Technologies
SB = Seals and Bearings
HM = Health Monitor
FP = Fabrication Processes

Probable Outcome/Increased Resources:
- Reduction in space transportation costs
- Low engine life-cycle costs
- U.S. pre-eminence in liquid rocket technology
- Defense effectiveness

FY 1987 Estimated Expenditures

The major sources of liquid rocket engine technology funding are the Air Force Astronautics Laboratory (AFAL), the NASA Marshall Space Flight Center (MSFC), Army Missile Command (MICOM), the NASA-Lewis Research Center, Strategic Defense Initiative Office (SDIO), and industry independent research and development (IR&D). In FY 1987, the estimated level of contract expenditures by these organizations was $80 million. FY 1987 contractor-funded technology expenditures are estimated at $20 million.

LIQUID ROCKET ENGINES

FY 1987 ESTIMATED EXPENDITURES*

FY 1987 Annual Level	Long Life	Low Cost	High Performance	High Reliability	Materials Application and Producibility
≥$5M/yr	MSFC/Lewis-Advanced Reusable Engine		AFAL-KEW MSFC-STBE/STME		
$3-5M/yr			AFAL-XLR-132 Storable Engine NASA/Lewis OTV Propulsion		
$2-3M/yr		AFAL-O_2/HC Engine	AFAL-XLR-134 Cryogenic Engine	MSFC/Lewis-Advanced Health Monitoring	
$1-2M/yr				AFAL Condition Monitoring	
<$1M/yr	← Many Individual Government and Industry Programs Totaling $20-30 Million Annually →				

*Includes DoD 6.1, 6.2, 6.3 type funding, does not include end-item development

The Foreign Competitive Threat

From the 1950s through the 1970s the U.S. was clearly the world leader in liquid rocket technology. However, in the 1980s, the USSR, the European Space Agency (ESA), Japan, and the People's Republic of China have been rapidly closing ground on the U.S. technology position. By the 1990s, U.S. leadership could be seriously challenged by advanced propulsion developments currently under way or planned by foreign competitors. Chemical propulsion system advances are being vigorously pursued for a broad range of applications, such as launch vehicles, upper stages, apogee kick motors, attitude control motors, satellite propulsion, etc., and include cryogenics, storables, hydrocarbons, bipropellants, and tripropellants. Capabilities that in the past resided exclusively in the U.S. could be matched, or perhaps exceeded, over the next few years. In Japan, gas generator, staged combustion, and expander-cycle oxygen/hydrogen engines are operational or under development. For example, the 265,000-lb vacuum thrust, staged combustion cycle LE-7 engine, that will approach the Space Shuttle Main Engine (SSME) capability, is being developed as the first stage engine for the new H-2 core vehicle, with the LE-5 as the second stage engine. The ESA Ariane family of launch vehicles has already made extensive use of storable propellant propulsion systems (Viking engines) and uses an HM7 oxygen/hydrogen engine as the third stage propulsion system. A new cryogenic upper stage engine development is planned to be used on the second stage of Ariane 5. The propulsion systems being developed by foreign competitors will lead to launch capabilities in the 1990s that will encompass most, if not all, of those of the U.S. family of launch vehicles at competitive costs and will provide them with the ability to compete for a large share of the world's space traffic, particularly to geosynchronous orbit.

The principal focus of liquid propulsion technology in the past has been on performance issues, such as achieving high engine thrust-to-weight ratios and high specific impulse (Isp) in order to maximize launch vehicle payload delivery capability. With chemical propulsion systems beginning to approach theoretical performance limits, technological advances need to focus on means for reducing propulsion development, production, and operation costs in order to help achieve a cost-competitive U.S. space transportation system. Engine development cost reductions should focus on means for minimizing development and certification hardware and testing, engine production cost reductions should focus on lower cost design and manufacturing techniques for both expendable and reusable engine designs, and operation cost reductions should focus on diagnostic techniques that will provide automated inspection techniques for reducing maintenance costs, automated preflight servicing, and checkout as well as automated inflight operations. Liquid propulsion technology focused in these directions will play a major role in reducing future launch vehicle life-cycle costs.

LIQUID ROCKET ENGINES

THE FOREIGN COMPETITIVE THREAT

- 1950s–1970s: U.S. clearly the leader
- Today: U.S. leadership seriously challenged
    - USSR leading in launches/year and payload to orbit
    - Japan
        - 1988 IOC for H-I booster
        - LE-5 LO_2/LH_2 engine for 2nd stage
        - LE-7 engine (for H-II Stage I) approaches SSME capabilities
    - ESA
        - Ariane family operational
        - HM7 3rd stage engine employs LO_2/LH_2
        - A new cryogenic engine replaces storable Stage II in Ariane 5

The Technology Roadmap provides direction for a technology foundation necessary to maintain the United States' competitive edge

Technology Challenges

Any technology as physically stressing as liquid rocket engines is wide open to technical advances. The tremendous forces and temperatures involved have been harnessed, of necessity, by essentially brute force, since suitable materials and analytical tools were not available. Unfortunately, the resources demanded by this approach have limited the attention given to the development of less conspicuous, high-leverage techniques, which often have a long maturation period and, thus, delayed payoff. The technologies here are essentially building blocks, underpinning the broad spectrum of liquid rocket engine technologies. Operational limitations are often ultimately traceable to such causes as a lack of understanding of a fluid dynamic process or the inability to adequately cool or lubricate a bearing. Developing and verifying advancements in the areas proposed herein will provide the tools and materials necessary to continue advances in liquid propellant rocket engine capabilities.

Achievement of national propulsion objectives for space activities and for effective military rocket systems will require demonstrated levels of flight reliability in all aspects of rocket operations, from manufacturing and test through launch procedures and flight. Although there are well-developed reliability methods (such as that by Taguchi) to assist the developer, they are unevenly applied. Future success will hinge on the integration of such practices throughout the development community. Since the techniques introduce additional participants and increased design iteration to the development process, successful implementation will entail "cultural" changes within the community.

LIQUID ROCKET ENGINES

TECHNOLOGY CHALLENGES

- Computation of coupled combustion and gas-dynamic processes
- Dynamic and steady loading/stress on high energy turbomachinery
- Solution methods for flow-structure coupling
- Modeling of flow-associated physics (e.g., turbulence)
- Thermal and dynamic modeling of bearings and seals
- Combustion stability prediction limited by understanding of combustion physics
- Material compatibility with propellants in the engine internal operating environment
- High strength, high temperature materials possessing high thermal conductivity
- Materials structural characterization
- Long-life propellant-cooled and lubricated bearings
- Propellant-compatible, high pressure, high temperature static and dynamic seals
- Fabrication processes, particularly material joining
- Use of reliability techniques in the development process

Program Goal

The goal of the Liquid Rocket Engine Technology Roadmap is to provide a technical base for reliable, high-performance, low life-cycle cost liquid rocket engines into the 1990s and beyond. The programs proposed will achieve this goal through development and validation of advanced capabilities prior to initiation of full-scale development. It is important to the success of this endeavor that the support activities—materials data base, engine test beds, and continuing commitment—be fully embodied in the program framework, as they constitute critical tools in the pursuit of this goal.

LIQUID ROCKET ENGINES

PROGRAM GOAL

- Provide core technologies prior to full-scale development

Essential Support:

- Expanded material data bases
- Engine test bed validation of Roadmap results
- Consistent core technology funding
- Extension of program beyond the 1990s

Result:

- U.S. pre-eminence based on lowered life-cycle costs

SOLID ROCKET MOTOR TECHNOLOGY ROADMAP

Definition

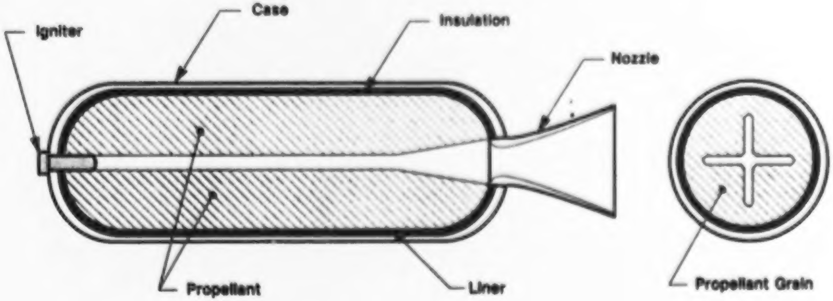
Solid rocket motors are a family of rocket propulsion systems characterized by use of a macroscopically homogeneous solid propellant grain containing both fuel and oxidizer constituents. Generally, the fuel is a hydrocarbon binder with metal powder, sometimes, but not always, containing a plasticizer and other additives, e.g., hydroxyl-terminated polybutadiene (HTPB) polymer and aluminum powder. The most widely used oxidizer is ammonium perchlorate (AP), although other oxidizers are used in several applications. Typically, by weight, a solid propellant is 10 to 15 percent binder and 60 to 70 percent oxidizer with the remainder being metal powders. The fuel, oxidizer, and other ingredients are mixed as a slurry then cast and cured directly in the rocket motor combustion chamber (case) in various geometric shapes (grain).

Basically, a solid rocket motor consists of five components—igniter, insulation, liner, case, propellant grain, and nozzle. For many applications TVC devices are also used.

Solid rocket motor technology, which also includes gas generators, is focused on improving the performance, producibility, and affordability of both components and solid rocket motors as a whole.

SOLID ROCKET MOTORS

SOLID ROCKET MOTOR


Case
Insulation
Igniter
Nozzle
Propellant
Liner
Propellant Grain

Technology Advancement Flow

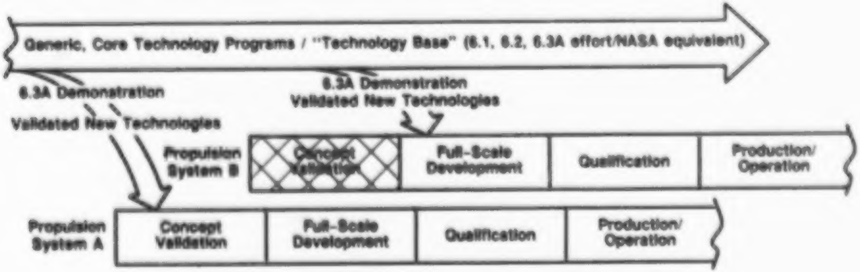
During the past decade, technology has generally been application oriented, i.e., technological effort has been focused on providing solutions associated with the development and production of specific motors. This type of research and development makes use of proven technology and methods to develop and produce the motor, but does not greatly advance the general understanding of solid rocket propulsion. It is also expensive and does not address the fundamental issues involved.

The most efficient and least expensive means of developing new motor concepts and designs is to have a dedicated force of scientists and engineers embarked in researching fundamental questions of solid rocket motor propulsion. There is a strong need for increased engineering technology which couples well-validated models with predictions and adequately instrumented tests, as well as strongly increased understanding of the processes used to make solid rocket motors, including the impact of processing variables on performance and reliability. These generic or core technology programs would be pushing beyond the current schedule of a specific motor program, but their results would be applicable to all motor development programs, solving problems in advance and making a higher base level of technology available.

Beginning a motor development program with a higher technological base means a higher quality motor for less cost in a shorter time. A better undersanding of core technologies will decrease life-cycle and operational costs and maximize flight reliability and safety because the technology has been proven in advance.

SOLID ROCKET MOTORS

OPTIMUM TECHNOLOGY ADVANCEMENT FLOW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Propulsion System A
Concept Validation
Full-Scale Development
Qualification
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Payoffs:
- Strong technology base
- Reduce development risk, cost, schedule
- Maximize operational success

Acronyms

As with any technology area, solid rocket motors have a wide range of acronyms. The most widely used acronyms and those used in this paper are given in the glossary. Acronyms generally apply to components, intended applications, or organizations.

SOLID ROCKET MOTORS

ACRONYMS

AFAL	Air Force Astronautics Laboratory
ALS	Advanced Launch System
AMI	Advanced Motor Instrumentation
ASRM	Advanced Solid Rocket Motor
AP	Ammonium Perchlorate
CAI	Computer-Aided Inspection
CAM	Computer-Aided Manufacturing
CIM	Computer-Integrated Manufacturing
CMDB	Composite Modified Double Base
CTPB	Carboxyl-Terminated Polybutadiene
ENEC	Extendible Nozzle Exit Cone
HCl	Hydrochloric Acid
Hi/Lo	High Performance/Low Observable
HLLV	Heavy Lift Launch Vehicle
HTPB	Hydroxyl-Terminated Polybutadiene
IDC	Insulation Design Code
IM	Insensitive Munitions

Isp	Specific Impulse
KEW	Kinetic Energy Weapon
"K" SERIES	KEW Series Programs
LCC	Life-Cycle Cost
MSFC	Marshall Space Flight Center
MICOM	U.S. Army Missile Command
NASA	National Aeronautics & Space Administration
NDE	Nondestructive Evaluation
NDI	Nondestructive Inspection
NWC	Naval Weapons Center
SPC	Statistical Process Control
SRM	Solid Rocket Motor
STAS	Space Transportation Architecture Study
TOD	Technical Objective Document
TPE	Thermoplastic Elastomer
TVC	Thrust Vector Control

Technology Elements

These elements constitute areas which will provide the high leverage necessary to significantly advance solid rocket motor technology.

Shuttle and Titan failures in 1986 underscored the national need for higher reliability, particularly for space vehicle launch propulsion. Future solid rocket motors for space launch vehicles must have reliabilities in excess of 0.999 at 95 percent confidence and at the same time be capable of being manufactured at significantly lower cost. The goal is to reduce solid rocket motor and associated operating costs so that the overall recurring cost of launching payloads is decreased by an order of magnitude relative to existing Space Shuttle and Titan baselines while improving reliability to at least 0.999 at 95 percent confidence.

The cost of failure and public pressure for failure-free operation of large rocket vehicles demand that we assure the public, as well as ourselves, that new propulsion systems are highly reliable. To do this, we must incorporate reliability into design, development, and manufacturing processes. This will require adaptation and use of statistical methods, such as those proven to be successful for automotive and electronic products, and a new emphasis on "reliability thinking" on the part of rocket design, development, and manufacturing engineers.

Other applications, satellite propulsion and KEW propulsion, will require significant improvements in motor performance—higher Isp, lower inert weight, and energy management. Delivered Isp greater than 315 lb-sec/lb, mass factions exceeding 0.95, and multi-pulse operation are realistic goals. In addition, many future propulsion systems, particularly for smart and brilliant tactical systems, will require energy management.

To achieve the above will require a better understanding of materials and processes than available today, increased use of computer-aided engineering, and wider use of automated manufacturing and quality assurance systems.

SOLID ROCKET MOTORS

TECHNOLOGY ELEMENTS

- Improved safety
- High reliability
- Reliability techniques
- Low cost
- High performance
- Automated manufacturing
- Quality assurance
- Energy management
- Low observables
- Insensitive systems
- Combustion dynamics

Technology Elements, Trends, and Milestones

There are two paths being pursued in advancing the state of the art of solid rocket motors. One emphasizes reliability and cost, accepting some reduction in achievable performance, while the other seeks means to improve performance. Both must be supported by automated manufacturing and quality systems.

Solid rocket motor problems encountered in the past have resulted from inadequate design/ analysis, unexpected combustion dynamics, process control, and/or extreme environmental/aging degradation. As an example, insulation design is a critical area for which an adequate design/analysis methodology does not currently exist. Relationships between nozzle materials, processes, and performance are also not sufficiently well understood. Improvements in design/analysis methodology and processes are needed for all motor components, along with more reliable and representative laboratory testing methods.

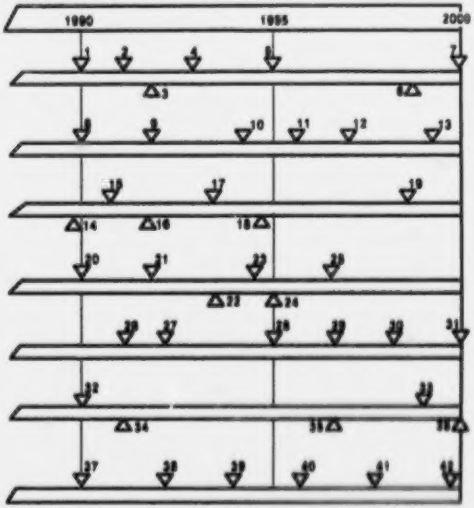
Low cost will require use of lower cost materials, e.g., TPE binders, and more producible designs for components and the motor as a whole. For space launch vehicles, low cost may place greater emphasis on reusability. In addition, introduction and effective use of automated process, on-line process monitors, statistical process control, and new approaches will be required to achieve the 0.99 reliability at 95 percent confidence and order of magnitude and cost reduction goals.

Higher performance will be required for satellite, KEW, and versatile ballistic and air-launched missile propulsion. For space and KEW propulsion, this means mass fractions in excess of 0.95, very compact lightweight TVC systems, and delivered I_{sp} greater than 315 lb-sec/lb. Energy management will be required for specialized applications. Tactical and strategic air-launched missiles will need improved performance maneuverability and flexibility coupled with improved reliability and lower cost. Combinations of high-energy propellants, compact lightweight TVC pulse motors, and reduced observables will be used to achieve these requirements. The emerging requirements for insensitive tactical systems must be addressed. Ballistic missiles will need advanced compact configurations for high-performance, high-acceleration operations. High reliability and low cost remain key issues.

SOLID ROCKET MOTORS

TECHNOLOGY ELEMENTS, TRENDS, AND MILESTONES

TECHNOLOGY ELEMENTS	TREND
High Reliability	Increased application of computer-aided models and AMI More comprehensive material and process data base
Combustion Dynamics	Standard ballistic data base Standard ballistic tests Early evaluation of new ingredients Improved models/codes
Low Cost	Low cost inert components Low cost propellant
High Performance	Lightweight inert components High energy propellants Energy management
Insensitive Systems	Increased "bullet" resistance Increased "cookoff" resistance Increased detonation resistance
Automated Manufacturing	CAM/CIM low cost methods
Quality Assurance	CAI techniques On-line process monitors Statistical process control *In situ* quality monitors (health monitors)
Validation	Demonstration motors Mission simulated conditions



△ / ▽ indicates completion of 6.2 and 6.3 effort or equivalent

TECHNOLOGY ELEMENTS AND MILESTONES

High Reliability	1	Improved 2D code, 1990
	2	Advanced motor instrumentation, 1991
	3	Existing materials and processes, 1992
	4	Insulation design code, 1993
	5	Improved 3D codes, 1995
	6	Advanced materials and processes, 1999
	7	Expert codes, 2000
Combustion Dynamics	8	Data base I, 1990
	9	Standard ballistic tests, 1992
	10	Data base II, 1994
	11	Advanced measurement tools, 1996
	12	New instability model, 1997
	13	Model/code verification, 1999
Low Cost	14	TPE propellant, 1990
	15	Low cost case, 1991
	16	Clean propellant, 1992
	17	Low cost nozzle/TVC, 1993
	18	Continuous mixing, 1995
	19	Component reusability, 1996

TECHNOLOGY ELEMENTS AND MILESTONES (Cont)

High Performance	20	Lightweight case, 1990
	21	Lightweight nozzle, 1992
	22	Compact TVC, 1993
	23	Multi-pulse, 1994
	24	Ultra-energy propellants, 1995
	25	Low observables, 1997
Insensitive Systems	26	Threat studies analysis, 1991
	27	Test methods, 1992
	28	Combustion mechanisms, 1995
	29	Mitigating devices, 1997
	30	Insensitive propellant baseline, 1998
	31	Insensitive system, 2000
Automated Manufacturing	32	SPC existing processes, 1990
	33	SPC new processes, 1999
Quality Assurance	34	On-line monitors, existing processes, 1991
	35	On-line monitors, new processes, 1997
	36	*In situ* monitors, 2000
Validation Motors	37-42	Every two years starting in 1990 Configurations to be determined

Benefits and Applications

The technologies discussed in this Roadmap are a mixture of analytical tools, improved automated manufacturing/quality assurance methods, improved materials, and component improvements with wide application to all systems that use solid rocket motors. For all applications, the following benefits will be realized:

- Improved payload or range
- Improved reliability
- Improved safety
- Reduced life-cycle costs
- Reduced development time

Other benefits, such as reduced environmental impact resulting from little or no HCl in the plume for space launch vehicle motors, as well as extended operating life, will also result for most other applications.

SOLID ROCKET MOTORS

BENEFITS AND APPLICATIONS

Benefits		Application				
		Space Launch Vehicles	Satellite Propulsion	Strategic Defense Missiles	Ballistic Missiles	Tactical Missiles
Lower Life-Cycle Costs	Improved Reliability	AT,MT,AQ, FP	AT,MT,AQ, FP	AT,MT,AQ, FP	AT,MT,AQ, FP	AT,MT,AQ
	Improved Safety	MT,AQ,FP	MT,AQ,FP	MT,AQ,FP	MT,AQ,FP	AQ,FP
	Extended Operating Life	MT,AQ	MT,AQ	MT,AQ	MT,AQ	MT,FP
	Reduced Development Cost/Time	AT,MT,AQ, FP	AT,MT,AQ, FP	AT,MT,FP	AT,MT,FP, AQ,	AT,MT,FP
	Reduced Environmental Impact	MT,FP			FP	

AT - Analytical Tools/Design Methodology
MT - Materials Technology
AQ - Automated Quality
FP - Fabrication Processes

Probable Outcome/Increased Resources:
- Reduction in space transportation costs
- Increased reliability and safety
- Lower life-cycle costs
- Improved defense effectiveness
- U.S. pre-eminence in solid rocket industry

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FY 1987 Estimated Expenditures

The major sources of solid rocket motor technology funding are the Air Force Astronautics Laboratory (AFAL), Marshall Space Flight Center (MSFC), Army Missile Command (MICOM), Naval Sea and Air Systems Commands (NAVSEA and NAVAIR), and Strategic Defense Initiative Office (SDIO). In FY 1987, the estimated level of contract expenditures by these organizations was $40 million for 6.1, 6.2, and 6.3 type programs. FY 1987 contractor-funded technology expenditures are estimated at $30 million (primarily IR&D). As can be seen, the majority of effort is in $1-2 million efforts.

SOLID ROCKET MOTORS

FY 1987 ESTIMATED EXPENDITURES*

FY 1987 Annual Level	High Reliability	Low Cost	High Performance	Automated Manufacturing	Quality Assurance
≥$5M/yr	MSFC-Nozzle Integrity				
$3-5M/yr	MSFC-ASRM				
$2-3M/yr		AFAL-Low Cost Propellant			Advanced Rocket Nozzle Inspection System
$1-2M/yr			AFAL-KEW AFAL-HIP/LO		
<$1M/yr	← Many Individual Government and Industry Programs Totaling $20-30 Million Annually →				

* Includes DoD 6.1, 6.2, 6.3 type funding, does not include end-item development

The Foreign Competitive Threat

There has been a significant increase during the last decade in foreign capabilities through company/government-sponsored efforts and infusion of U.S. technology. At present, 22 countries have various degrees of solid rocket capability.

England, France, West Germany, Norway, Italy, and Japan are now firmly entrenched in the tactical missile propulsion area through company/government-sponsored effort and U.S./MOU programs, e.g., Maverick, Patriot, Sidewinder.

Italy, France, and Japan are also firmly entrenched in the large motor area (up to 90 in. diameter) through company/government-sponsored efforts, e.g., Ariane, "N," "H" vehicle strap-ons.

France and Japan are now firmly entrenched in the satellite propulsion area through company/government-sponsored efforts, e.g., STAR motor "look alikes"—STAR 30, 37.

International competition, although varying from country to country (Japan and France considered the most advanced), is judged on a part with U.S. state of the art in design, quality control, and producibility of inert components. France is considered ahead on carbon-carbon component technology since that technology is now being imported into this country by Hercules and Kaiser, for example. Competing countries are rated behind the U.S. in propellant technology, particularly for high energy systems. In lower energy systems they are approaching the level of the U.S. with CTPB, HTPB, and CMDB propellants.

U.S. technology is obtained by other countries through numerous forums, e.g., AIAA, SAE, and SAMPE meetings, and MOU programs.

SOLID ROCKET MOTORS

THE FOREIGN COMPETITIVE THREAT

- Significant increase in both European and Japanese capabilities in the last decade
- England, France, West Germany, Italy, Norway, and Japan entrenched in tactical missile propulsion
- Italy, France, and Japan entrenched in space launch vehicle propulsion area
- France and Japan entrenched in satellite propulsion area
- International competition is increasing
- International competition is judged on a par with U.S. state of the art in design, quality control, and producibility of most inert components
- France considered ahead on carbon-carbon component technology
- International competition approaching par on propellant technology except for high energy systems
- U.S. technology is transferred through numerous forums, e.g., AIAA, SAE, and SAMPE meetings, and MOU programs

Technology Challenges

The list of technology challenges is long. Each represents an essential area of effort to meet future national needs. Each should be pursued. Unfortunately, the resources demanded by such an approach have previously limited the attention given to development of less conspicuous, high-leverage technology which has a long maturation period and, therefore, delayed payoff.

Achievement of national propulsion objectives for space activities and for effective military rocket systems will require demonstrated levels of flight reliability in all aspects of rocket operations, from manufacturing and test through launch procedures and flight. Although there are well-developed reliability methods (such as that by Taguchi) to assist the developer, they are unevenly applied. Future success will hinge on the integration of such practices throughout the development community. Since the techniques introduce additional participants and increased design iteration to the development process, successful implementation will entail "cultural" changes within the community.

Developing and demonstrating the advancements in the areas listed will provide the tools, materials processes, and quality techniques necessary to continue advances in solid rocket motor technology.

SOLID ROCKET MOTORS

TECHNOLOGY CHALLENGES

- Insensitive systems
- Improved bond systems
- Improved nonlinear 2D/3D computer codes
- Improved insulation design codes
- Expert computer codes
- Strain-induced combustion effects
- Comprehensive material and process data base
- Material process/property interrelationship
- Structural material failure criteria
- Low cost cases
- Low cost nozzle/TVC systems
- Low cost propellants
- "Clean" propellants
- Compact TVC systems
- Ultra-energy propellants
- Automated NDI/NDE
- On-line process monitors
- Laboratory/subscale motor interrelationships
- Demonstration motors
- Improved *in situ* instrumentation
- Use of reliability techniques in the development process
- Improved reliability demonstration procedures
- Low observables
- Energy management

Comparison with Government Studies

The effort proposed is in substantial agreement with a number of NASA, Navy, and Air Force studies.

SOLID ROCKET MOTORS

COMPARISON WITH GOVERNMENT STUDIES

The effort proposed is in substantial support of the following government studies:

- Air Force/NASA — Space Transportation Architecture Study (STAS)
- Air Force/NASA — Heavy Lift Launch Vehicle Study (HLLV)
- Air Force/NASA — Advanced Launch System Study (ALS)
- Air Force — Rocket Propulsion Technical Object Document (TOD)
- NASA — Solid Propulsion Integrity Program Technical Plan (SPIP)
- Navy — NAVAIR Air Weaponry Analyses

Program Goals

Over a 10-year period, with adequate resources, the listed program goals are considered a challenge, but achievable.

SOLID ROCKET MOTORS

PROGRAM GOALS

Parameters	Goal
High Reliability	>0.999 at 95 percent confidence
Low Cost	Order of magnitude reduction in recurring cost per pound delivered to orbit Significant reduction in tactical and strategic propulsion costs
High Performance*	
Mass Fraction	>0.95
Nozzle Expansion Ratio	>1[illegible]:1
Delivered I_{sp}	>315 lb-sec/lb
Automated Manufacturing	60 percent reduction in nonvalue-added labor Significant safety and quality improvement
Quality Assurance	Automated measurement, recording of attributes against "accept/reject" standards
Operational Life	20 years +
Safety	Insensitive
Mission Flexibility	Multi-pulse operation

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*Upper stage and space-launched motors

ROCKET PROPULSION ADDED EFFORT REQUIRED, CONCLUSIONS, AND RECOMMENDATIONS

Added Effort Required

To achieve the goals outlined in this Technology Roadmap, a consistent expenditure of approximately $300 million per year over ten years from all sources is required. In order to realize the goal of lowered life-cycle costs by emphasizing research that is not program-specific, the expenditure and the number of personnel must be consistent from year to year.

We recognize that significant funding is planned under the Advanced Launch System (ALS) program. However, this is "focused technology" and, although "fallout" will result, the generic output of such programs is, of necessity, seldom of sufficient breadth to be of wide benefit. The NASA Civil Space Technology Initiative (CSTI) is an example of the type of effort required.

Both government and industry test and facilities need to be upgraded and put into operation and there must be a greater use of demonstration/validation engines and motors and advanced instrumentation to validate the concepts that result from a consistent core technology research program. There also needs to be more cooperation between government, industry, and the academic community in establishing and utilizing supercomputer centers. The NASA-Ames supercomputer and the NSF Supercomputer Centers around the country are notable achievements toward the realization of this goal, but additional facilities are needed.

The establishment and maintenance of a rocket material data base is also a necessity and will require a working group consisting of industry, universities, and government, as well as groups such as Battelle, ASTM, DoD Information Analysis Centers, SAMPE, etc., to ensure the proper organization and upkeep.

There needs to be increased recruitment of new science and engineering graduate students and greater cooperative involvement with academia.

ROCKET PROPULSION

ADDED EFFORT REQUIRED

- Consistent annual expenditure of $300 million per year devoted to generic core technologies and their demonstration*
- Test facilities capable of mission simulation
- Special component technology test stands (e.g., turbopumps)
- New methodology for reliability demonstration and validation
- Expanded government/industry/academic supercomputer cooperation
- Order of magnitude expansion of engineering data base
- National material data base
- Greater academic involvement, cooperative ventures

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*The ALS "focused" technology has applicability; the NASA CSTI program will provide a good start

Conclusions

The stated national goals of reducing space transportation costs by an order of magnitude, having a viable space defense system, and maintaining a strong defense posture cannot be supported by today's technology. "Business as usual" FY 1987 level funding and facilities will not obtain the enabling technology to support national needs. At least a threefold, long-term commitment compared to FY 1987 is required. Without such a commitment, the country will lose its pre-eminence in rocket propulsion technology early in the next century and will fail to meet national needs. The recommended technologies can provide significant leverage to rocket propulsion development programs by enabling performance advances without sacrificing cost and reliability goals.

ROCKET PROPULSION

CONCLUSIONS

- There are supporting technologies which can provide considerable leverage to the development of advanced rocket propulsion systems
- These technologies, when validated by test bed demonstrations, will provide a firm base for confident initiation of development programs
- Formulation of the specific technology development plans to be pursued must involve government, industry, and the academic community. Plans should include consideration for rocket materials and processes data bases and textbooks for rocket design and safety practices
- Continued and consistent support of generic technology advancement is necessary to realize Roadmap goals
- The benefits derived from these areas can provide the edge to retain our leadership in rocket propulsion in the international marketplace

Recommendations

Whereas DoD and NASA have plans for development of rocket propulsion systems and their major components, there is no such arrangement for the technologies proposed herein. Since they are of universal application to the rocket propulsion industry, they are a logical choice for cooperative efforts. However, commercial revenues are not sufficient to support the range of technology required, and with current ceilings on IR&D, industry funds are severely limited. Therefore, it is recommended that government agencies undertake to foster this work to reap the benefits of the leverage that it provides. In addition to providing direct support, this should include easing the IR&D ceilings to enable expanded industry participation. More academic involvement is also essential to meeting the technology goals. Demonstrations of the new technologies in test beds prior to full-scale development is crucial to gaining confidence that the technologies are ready for application.

ROCKET PROPULSION

RECOMMENDATIONS

- Establish a long-term commitment to technology advances necessary to maintain technological excellence and meet national needs
- Formulate specific technology development plans which yield necessary technologies that support national missions and goals
- Involve industry, government, and the academic community in the planning to ensure inclusion of other ongoing programs
- Embody these technologies in test bed programs prior to full-scale development to ensure that the advances evolved are validated in a system environment. Utilize existing government facilities as appropriate. Modify or build new facilities as necessary to satisfy future mission needs

May 25, 1989

The Honorable Doug Walgren, Chairman
Subcommittee on Science, Research and Technology
2319 Rayburn House Office Building
U.S. House of Representatives
Washington, D.C. 20515

Dear Mr. Chairman:

As a witness before the Subcommittee on Science, Research and Technology on May 18, 1989, Congressman Tom Campbell asked me for my comments on Treasury Regulation 1.861-8. On line 2121 of Page 93 of the hearing transcript, I indicated that I was not prepared to address the question. In this letter I would like to respond to Congressman Campbell's question and submit it for testimony in the form of an appendix.

Under the 861 regulations, Apple must treat a portion of our domestic R&D expenditures as if it were conducted abroad. While domestic R&D efforts do indeed benefit our sales worldwide, it is impossible to get a foreign jurisdiction to consider R&D conducted in the U.S. as an expense against sales income in the foreign country. These countries argue that if we conducted the R&D in the U.S., then we should get the tax break from the U.S., not from their country. Moreover, they are trying to leverage off of such U.S. tax policy to force U.S. companies to invest R&D facilities in their country. They argue that if U.S. tax policy treats U.S. R&D as if a portion of it were performed abroad, then we should move that portion to their country where we can at least get the tax benefit from it!

Apple already faces tremendous pressure from foreign countries to increase investment abroad in exchange for market access. Currently, India is denying us market access for microcomputers unless we set up a joint-venture with an Indian firm. In Australia, a new law now requires that foreign firms conduct research and development in Australia in order to maintain market access. In Canada, we cannot sell to certain government agencies unless we increase Apple's investment there. Consequently, our employees look for local technologies that Apple can support in lieu of building an R&D facility there. With foreign governments coercing U.S. companies to move R&D to their country, we do not welcome the 861 regulations which act as a disincentive to conducting R&D at home.

Apple Computer, Inc.
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Washington, D.C. [illegible]
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Recognizing the onerous effect of these regulations, Congress has repeatedly adopted temporary moratoriums to prevent the implementation of the 861 regulations. But a permanent solution has yet to be adopted. It is the permanent solution to this regulation that we are seeking in legislation soon to be introduced by Congressman Beryl Anthony.

If you have further questions on this issue and how it affects Apple Computer, Inc., do not hesitate to call me.

Sincerely,

Bill Poulos

Bill Poulos
Manager, Government Affairs